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THE TEACHING OF GENERAL SCIENCE IN TROPICAL SECONDARY SCHOOLS

THE TEACHING OF GENERAL SCIENCE IN TROPICAL SECONDARY SCHOOLS

by

H. N. SAUNDERS

Being VOLUME VII *of the*
UNESCO HANDBOOKS
ON THE TEACHING OF SCIENCE
IN TROPICAL COUNTRIES
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General Introduction

Scientific discoveries, and their applications in industry, communications, agriculture, medicine and war, have caused great changes in the lives and habits of most of mankind during the last 150 years. Men's ways of thought are not yet accustomed to this change.

Because of the destructive power of some scientific inventions, many men have lost faith in the future of mankind; because of the marvellous power of other scientific inventions to increase the well-being of mankind, many men have expected Science to find an answer to all life's problems. Both of these views of Science show a misunderstanding of what Science is and what scientists can or cannot do. How can such misunderstandings be prevented?

It is not enough to train expert scientists; they are necessary, but it is equally necessary that ordinary folk should know what scientists try to do and how they try to do it. Before they can understand the scientists' work, non-scientists must first learn what Science is. For this, a knowledge of scientific facts and principles is not as important as an understanding of Science and the methods used in its study. And this understanding of Science must become a part of men's everyday life and thought.

Understanding comes through education; but the understanding of Science must not remain merely an aim of education: it must become part of it. In schools, isolated courses in one or another aspect of science must be replaced by a view of Science as a whole and of its part in learning.

That is the basis of the project, in this series of books, to advise and help teachers of Science. The emphasis is put on methods of teaching and lines of approach to the subject matter, rather than on the content of a syllabus. It is hoped that, by the use of good methods, the teacher will be able to lead his pupils towards an appreciation of scientific methods and an understanding of Science. Through sound education, not only will the few receive the basic training that will fit them for specialization later, but the many will grow up with an intelligent grasp of Science and its significance in their social and economic life.

THE SCOPE OF THE SERIES

There are ten volumes in the series, designed specially for Science teachers in tropical areas and countries that are not yet highly organized and industrialized, and where the applications of Science are not yet apparent in the daily life of all citizens:—

I The Teaching of Science in Tropical Primary Schools
II The Teaching of Rural Science in Tropical Primary Schools
III The Teaching of Health Science in Tropical Primary Schools
IV The Teaching of Home Science in Tropical Primary Schools
V The Teaching of Arithmetic in Tropical Primary Schools
VI The Training of Primary School Science Teachers
VII The Teaching of General Science in Tropical Secondary Schools
VIII The Teaching of Physics in Tropical Secondary Schools
IX The Teaching of Chemistry in Tropical Secondary Schools
X The Teaching of Biology in Tropical Secondary Schools

Volume I is concerned with the teaching of Science to children in the age-group 6–12 approximately, who are receiving their first formal education. It is designed for students in teacher-training colleges and practising teachers in primary schools. They are shown how to make the most of the children's natural interests.

Volumes II, III and IV also are written mainly for the benefit of the primary school teacher. They treat Science at the same level as Volume I, but from different aspects. Thus, Volume II is of especial value to teachers in rural schools: it does not give instruction about the teaching of 'Farming' or 'Agriculture', but uses these activities to give practical examples of scientific methods and principles in action. Similarly, in Volume III the importance of Health is the theme of Science teaching. The book will help any teacher, and will be of particular use to those in places where great efforts are being or should be made to raise standards of health. Volume IV associates the teaching of Science with life in the home, as the basis of a Science course for girls.

Volume V deals with the fundamentals of Arithmetic as an essential component of Science.

Volume VI is concerned with the training of teachers who are to give the science lessons in Primary Schools, and who, it is hoped, will adopt the methods suggested to them in Volumes I to V.

Volume VII carries the teaching of General Science to the earlier years of a secondary course; 4–5 years in the age-group 11–18 approximately. It shows how the work can be regarded both as a course of educational value for its own sake and also as a foundation for further studies. It gives full information on laboratory design and organization, minimum equipment, and maintenance.

Volumes VIII, IX and X discuss the teaching of the three branches of Science usually taught in the higher classes of secondary schools. The place and treatment of these subjects in junior work also is considered briefly. The chief aim of these three volumes is to assist the teacher of students who are beginning to specialize, probably with a university career in view, i.e. those who are undertaking 'sixth-form' or 'scholarship' or 'first-year undergraduate' studies.

THE AIMS OF THE SERIES

Thus, the intention of this series of books may be summarized as follows:—

(*a*) To help teachers of Science to realize the importance of their work in the community; to help them to guide their pupils to an understanding of the significance of everyday occurrences and experience; and so to educate them to take an intelligent interest in social and economic affairs and to be useful members of their community.

(*b*) To show how Science instruction can be organized as a continuous whole, in accordance with modern views of co-ordinated teaching, and how it can be adapted to meet any special requirements of a particular type of school.

(*c*) To suggest a comprehensive scheme of teaching based on sound educational and psychological principles.

(*d*) On the basis of the practical teaching experience of the authors and the general editor and their advisers, to outline the content of Science teaching from the Primary to the Pre-University level.

This series originates in the need, so often expressed to the United Nations Educational Scientific and Cultural Organization, especially by those responsible for education in tropical countries, for more and better science teaching in primary and secondary schools. These educationists share world-wide opinion that training in Science is essential to modern education, to the improvement of health and living conditions and the promotion of agriculture and industry. In response to their appeal Unesco conceived the plan and the method of presentation of the series and subsidized the preparation of the ten manuscripts. Responsibility for choosing the authors and the general editor and for the cost of publication was undertaken by the Oxford University Press in agreement with Unesco.

Preface to Volume VII

This book deals with the teaching of Science to pupils in their first three, four or five years at the secondary stage: that is, with the instruction of boys and girls in the age-group 11–18. Thus it is concerned with the type of work which is a continuation of the primary courses considered in Volumes I to V of this series. (Teachers of pupils who have received no elementary introduction to Science would be well advised to refer to those volumes. If such children are to gain full benefit from a secondary course, it is essential to 'fill in the background'.)

The book is intended to give particular help to the young teacher, or the teacher-in-training, in presenting Science as a whole rather than several separate 'subjects', and as an integral part of the school curriculum. By adopting this broad outlook, and treating his material accordingly, the teacher is more likely to achieve his main objective—the development in his pupils of some genuine understanding of Science. A further aim is to provide useful information and advice for those who teach under difficult conditions.

A teacher's work cannot be effective or successful unless what he teaches is part of himself. However widely he may read, whatever the model lessons he may use for guidance, his General Science teaching does not become vital until it is *his* experiment, *his* contrivance, *his* method which are being used. Hence it is hoped that the material offered here will stimulate as well as guide, and will encourage the teacher to try out things for himself as well as provide a source of information.

The originators of some of the suggestions given in these pages have been forgotten and cannot be thanked by name. It is possible only to pay tribute to their enthusiasm and skill, and to hope that those who devise new experiments, contrivances and methods for the better teaching of General Science will be equally willing to share them with their fellow teachers.

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A long succession of the author's pupils, of many races and in various parts of the world, have played their unwitting part in the composition of this book. To them, and to his own children, the volume is dedicated.

H. N. SAUNDERS

Mfantsipim School,
Cape Coast,
Gold Coast,
1954

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CHAPTER I

Science in the World

The values of science in modern life

Practical value—The practical value of scientific knowledge forces itself on the attention at every turn. New areas of the world are being opened up for cultivation and development as a result of recent discoveries in genetics and soil chemistry. Scientists have discovered new materials and have devised new methods, so that fresh industries are arising and the old balances of trade and commerce are being readjusted. The history of our own times is being profoundly affected by the development of rapid means of travel, and by the speed with which ideas, both true and false, can be spread to every part of the world. Many tasks, from the dating of fossils to the assessment of the value of unexploited oilfields, have been simplified by the use of new methods which scientists have placed in the hands of workers. It is true that one product of the scientists' invention, the atom bomb, may be used to destroy large areas of the world. On the other hand the scientists can provide the means to feed the earth's ever-increasing population, which otherwise will be in danger of perishing from starvation.

① agric
② indu
③ tran
④ com
⑤ better tech

Intellectual value—Science has more than the obvious practical effects to offer. It has its own disciplines. Its pursuit requires diligence and patience. The scientist must have a high regard for truth; he must base his judgements upon facts alone and must not be misled by prejudice. He must be willing to subject his claims, his arguments and his conclusions to the searching examination of any who may care to challenge them. Politicians and economists, administrators and men of commerce, and all who are involved in public life, may sometimes find it hard to imitate the calm detachment and unemotional judgements of men of science. But the existence of a body of men devoted to the pursuit of truth cannot fail to have its effect upon the whole of a nation's life.

① discipl
② diligen
③ patien
④ objectiv judgem
⑤ critical thinking
⑥ detachm
⑦ unemoti view

Aesthetic value—There is an aesthetic side to the scientist's activities and to his contribution to human culture. On the lowest level he has the satisfaction of adding to the sum of human knowledge. On a higher level he enjoys the subtle pleasure of devising some hypothesis which fits a diversity of facts, and of opening up new areas of knowledge. Appreciation of 'fitness for purpose', the suitability of an apparatus for the job for which it was designed, can give great inward satisfaction. There is a pleasing skill in avoiding or eliminating sources of error, and in particular the errors of human observations. Wonder is aroused by the neatness with which some material quality, or some living activity, can be sorted out from other qualities or activities for examination and demonstration. There is an elegance that runs through the logic and handiwork of scientists. It is seen in the formulae of the mathematicians; it is equally seen in the experiments and observations of the great naturalists. The very simplicity of the great generalizations of science stirs the imagination. With microscope and telescope the scientist opens up new worlds of wonder and beauty. A speck of living matter becomes a creature of incredible beauty, a snowflake more lovely than diamonds; a distant star becomes a universe. It is at this level that science shares, equally with the arts, the privilege of contributing to the aesthetic development of the human race.

The extent of scientific enquiry

Scientists are interested in a wide range of knowledge.

First comes MATHEMATICS. Its logical methods provide the apparatus by which all scientific calculations are made.

That branch of MECHANICS called DYNAMICS deals with the application of mathematics to the study of things that move, the calculation of velocities and accelerations, of work and horse-power. Another branch, called STATICS, is concerned with conditions under which forces are balanced, how bridges support weights and cranes carry loads. HYDRODYNAMICS and HYDROSTATICS deal with calculations about fluids in motion and at rest.

PHYSICS deals with the measurement of the various properties of material things: their density, resistance to bending or stretching, their ability to retain heat or to conduct it, and the heat changes that take place when substances melt or boil. Physics also deals with the measurement of the speed of light and the properties of lenses; with the speed of sound and the frequency of its vibrations. The numerous effects of electricity give the physicist wide scope for measurements of many kinds.

CHEMISTRY, relying a great deal upon information supplied by the physicist, is concerned with what happens when materials change their composition: for instance, what happens when iron changes into rust, or chalk is made into lime, or when an organism digests a complex food. For in all these changes a change in the grouping of atoms takes place. The physicist sees matter in three forms, solid, liquid or gas. But the chemist divides matter into two types, elements and compounds: elements cannot be analysed into anything simpler; compounds are made up of two or more simple substances, more closely joined together than is possible by mere mixing.

ASTRONOMY deals with matter on the very large scale seen in the universe. It is concerned with the arrangement and movement of the heavenly bodies, and the physical and chemical changes taking place in them.

With the study of BIOLOGY the scientist, for the first time, asks questions about the nature of living things, and how they affect, and are affected by, their surroundings. This 'science of living things', which is what the word 'biology' means, may deal mainly with plants, when it is called BOTANY, or with animals, when it is called ZOOLOGY, or with bacteria, when it is called BACTERIOLOGY, and so on. There are many sub-divisions.

There is no exact dividing line between the sciences. Sometimes the area of common knowledge and interest is given a special name. The chemist may be interested in those physical measurements which help him to find the composition of the chemical with which he is dealing. That area of knowledge is called PHYSICAL CHEMISTRY. The biologist may be studying the chemical changes which take place in living cells, and that area of knowledge is named BIO-CHEMISTRY.

The process of selecting a small fraction of knowledge and giving it the status of a separate 'science' continues apace, as indeed it must as long as the knowledge that scientists are gaining continues to accumulate so fast. The whole is far beyond the grasp of any one mind.

A chart indicating the connexions between some of the sciences is given in Figure 1, page 4.

SCIENCE AND ITS APPLICATIONS

Some of the sciences		*Some of their applications*	
	MATHEMATICS		Statistics
ASTRONOMY			Navigation
METEOROLOGY			Surveying
MECHANICS		*Mechanical Engineering*	Aeronautical Marine Railway Automobile etc.
	PHYSICS		
		Electrical Engineering	Telecommunications Power generation Power transmission etc.
		Civil Engineering	Roads, bridges, docks Water supplies Sewage disposal etc.
		Architecture	
PHYSICAL INORGANIC ORGANIC	*CHEMISTRY*	*Chemical Engineering*	Electro-chemical processes Coal products Petroleum products Synthetic fibres, rubber, drugs, etc. Explosives Oils and fats Soap Food industries
		Pharmacy	
BIO-CHEMISTRY ZOOLOGY		*Medicine*	Pathology Surgery Dentistry
BOTANY	*BIOLOGY*	*Veterinary Science*	Fisheries Husbandry Genetics
		Agriculture	Forestry Crops Soil science
	GEOLOGY	*Metallurgy*	Extraction of metals
MINERALOGY		*Mining*	

FIGURE 1.—A chart: indicating connexions between some of the many ‘sciences’ and their sub-divisions

The assumptions of science

Scientists make two assumptions: that there is a reason for everything that happens, and that the same causes will always bring about the same results if the conditions are unaltered. Faith in the first assumption gives the scientist hope and encouragement in his endless seeking; faith in the second makes it possible for other scientists to repeat the experiments which have been carried out, in order to check the results.

The limitations of science

There is, however, a vast range of knowledge and experience from which the scientist, as a scientist, cuts himself off. He concerns himself with the material facts of the universe and the order of its development, but not with the reason for its beginning or the goal ① of its ending. He is interested in living things, and how they fit into the existing scheme of things, but not in the question of why they exist at all. He is interested in things, but not in values; in how to make an atom bomb, but not in the rightness or wrongness of its use. To him, as a scientist, marble is calcium carbonate, whether it be a discarded chipping from a quarry, or a Greek statue.

Science is not concerned with describing things as 'good' or 'evil'. ② Nor is it concerned with actions to which the words 'ought' or 'ought not' are appropriate. As a private individual the scientist may be deeply concerned about all these matters, but his scientific experience does not qualify him to give an expert opinion, and his judgement is of no more value than that of an intelligent person in any other trade or profession. In fact his opinion on such matters is of much less value than that of an intelligent person who has made a special study of these problems.

The modern scientist, though proud of his calling and zealous in the search for truth, is yet a humble man. He knows that all for which he labours is, at the most, but one facet of truth. He is willing to ③ suspend judgement in problems outside the scope of his limited interests. And among the wisest there are some who are, as Darwin was, acutely regretful that the years spent in the pursuit of scientific knowledge have left them with too little acquaintance with music, literature, poetry, and the art of gracious living.

His specialist knowledge may be limited in range. Yet, in so far as his passion for truth and his ability to marshal facts and to draw logical conclusions are transferable attitudes and skills, the scientist makes a contribution to the world that is second to none.

There is limitation in science itself, and because of it the science teacher is often required to make a difficult decision. The teacher, and in due course, the student, must realize that what the scientist produces as an 'explanation' is not an explanation at all. The scientist merely puts similar phenomena into the same pigeon-hole, or at most takes the question only one stage nearer solution.

Water rises up a narrow glass tube. Why? Because of surface tension. Should the teacher pursue the matter further or should he be content to leave it there? After all, the phenomenon has been noted, docketed and filed, and placed in this pigeon-hole labelled 'surface tension', along, maybe, with facts about drops, the shape of a meniscus, pressure inside bubbles, certain water-beetles, and so on. Now it is quite legitimate for the teacher to leave it there, provided that he realizes that the question, 'Why does water rise up a narrow glass tube?' has not been fully answered. He should be prepared to admit this, even if he takes no active steps to demonstrate that, so far as his knowledge is concerned or the syllabus demands, all have arrived at an educational terminus.

But the better equipped teacher dare not 'leave it there'. Plainly, and of his own initiative, he should go on to ask, or elicit from the class, the question, 'But what causes surface tension?' And the answer is, 'attraction between the molecules of which matter is made up'. This answer, too, only puts the problem one stage nearer solution. For the next question is obviously, 'Why do molecules attract one another?' If the answer is given that 'all bodies attract one another', that only puts the phenomenon in the pigeon-hole with many other evidences of gravitational forces, it does not *explain* why gravity acts as it does. Instances could be multiplied.

But how far and how frequently these skirmishes into the unknown should be made must remain a matter for the teacher to judge. His own limitations, the age and alertness of his class, the restrictions of time-table and curriculum, are the factors which will govern his decision. But when an intelligent class becomes suddenly aware that the usual answers merely push the problem one stage backwards, and the teacher and the class join in the chase for the ultimate answer, the experience for both teacher and class is an exhilarating one.

The methods of science

It is the business of the scientist to accumulate knowledge about the universe and all that is in it, and to find, if he is able, common factors which underlie and account for the facts which he knows. He chooses, when he can, the method of the 'controlled experiment'. If he wants to find out the effect of light on growing plants, he takes many plants, as alike as possible. Some he stands in the sun, some in the shade, some in the dark; all the time keeping all other conditions (temperature, moisture, nourishment) the same. In this way, by keeping other conditions constant, and by varying the light only, the effect of light on the plants can be clearly seen. This method of using 'controls' can be applied to a variety of situations, and can be used to find the answers to questions as widely different as 'Must moisture be present if iron is to rust?' and 'Which variety of beans gives the greatest yield in one season?'

In the course of his inquiries the scientist may find what he thinks is one common explanation for an increasing number of facts. The explanation, if it seems consistently to fit the various facts, is called a *hypothesis*. If a hypothesis continues to stand the test of numerous experiments and remains unshaken, it becomes a *law*.

The 'laws' of science differ from the 'laws' of a country in two ways. First, a scientific law is liable at any time to need modifying. This happens when a fact is discovered which seems to contradict what the 'law' would lead one to expect. The 'law' may, in fact, have to be abandoned altogether. Second, a scientific 'law' says 'This is likely to be the explanation', or 'This accounts for the facts as far as we know them'. But the 'law' of a country says 'You must . . .', or 'You must not . . .' The scientific 'law' has no moral force; it is not binding on human behaviour nor approved or opposed by human conscience.

The scientist is always most gratified to find that an underlying 'explanation' of many phenomena suggests in its turn the possibility of proving, without more ado, its own accuracy or falsity by a suitably arranged critical experiment. He is also gratified when his 'explanation', if true, points to a new series of experiments designed to answer a new set of questions. For the curiosity of the scientist is never satisfied.

The rapid increase of scientific knowledge

The evidence as to the vastness of the universe and the complexity of its arrangements continues to grow at an amazing rate. The gap between what we know and all that can be known seems not to diminish, but rather to increase with every new discovery. Fresh unexplored regions are for ever opening out.

The rapidity of the increase of scientific knowledge, in the nineteenth and twentieth centuries, is apt to give students and teachers the impression that no sooner is a problem stated than the answer is forthcoming. A historical chart such as that in Appendix A, page 283, summarizes some of the main advances in our knowledge, and at first sight almost appears to confirm this wrong assumption. A more detailed study of the history of science corrects the impression that fundamental discoveries are made with dramatic suddenness. Even in our present age no less than fifty years separate the discovery of radio-activity from the explosion of the first atomic bomb. Much of the fundamental information which now enables us to control the onset and duration of disease was known a century ago. The teacher, giving his brief accounts of scientific discovery, is apt to forget the long periods of misunderstanding, of false hypotheses and general uncertainty, which almost invariably precede the clear statement of scientific truth.

The challenge of unsolved problems

The vast mass of information which the scientists have gained has still not provided the answer to the fundamental questions which, through the centuries, have puzzled and sometimes tortured the human mind. There are many such questions. For example, how do we see? We know that light is focused by the lens of the eye on the retina, where it stimulates chemical activity, which in turn sets up electric currents in the nerve ends comprising the retina. We know that these currents, after passing through intricate interconnexions, travel to the brain along a bundle of nerves called the optic nerve. But the deeper, unsolved problem is: how does the brain interpret the innumerable electric impulses in such a way that we say 'I see a house' or 'I see boys playing with a ball'? Where lies the common brain which determines the proportionate activities of the various members of an anthill or a beehive? The study of parasites has provided evidence that organisms which could be self-supporting have become parasites, but hardly any light has been shed on the problem of why they should have done so. What enables an organism to respond to the poisonous secretions of harmful bacteria and organize its resources to defend its life? What enables a complex organism to extract, out of one blood stream, materials appropriate to building bone tissue here and to renewing muscle tissue there? What orders the mechanism so that hormones are sent into the blood and living tissues respond?

The effect of living organisms on their surroundings, the sequence of life-processes, the constitution of living cells, the mechanics of heredity, are better known every day. But the nature of the 'life-force' is as obscure as ever. What makes the difference so that we say of this, 'It is dead', and of that, 'It is alive'? Our ability to control disease is evident on every hand, but why animate nature should be plagued with disease at all is shrouded in mystery.

When the teacher deals with the immature and impatient minds of younger children he may well emphasize the 'wonders' of science, its conquests and its triumphs. But the minds of more mature students are often best stimulated by being made aware of man's ignorance, rather than by being given accounts of man's knowledge. It is the superior mind which is attracted by the unknown.

The need for science

There are countries in which unnecessary poverty prevails because the people as a whole are unaware of methods whereby it can be relieved. There are vast tracts of land, abandoned or never cultivated, which could support a thriving community if full use were made of the knowledge and skill of scientists. There are innumerable people suffering from diseases which can be cured, and from which, by following simple scientific rules of hygiene, they need never again suffer. There are vast storehouses of natural power, such as the wind, waterfalls and the heat of the sun, which science can show how to harness for the relief of human drudgery and for raising the standard of living. The possibilities are enormous.

But the difficulties in the way of effecting a change for the better are not less enormous and are often overlooked. The full benefits of science can only be gained with the co-operation of the people in need of assistance. That co-operation is regrettably ineffective unless the people also have some understanding of the means used. A sterilized bandage brings no cure to an infected wound. It is all too easy for the ignorant to believe that fifty doses of medicine, taken at once, will produce a cure fifty times as fast as a single dose taken on fifty successive occasions. Farm machinery, broken down and neglected for lack of skilled mechanics, can be a source of loss rather than of profit. The finest seed, sown at the wrong time or under the wrong conditions, may have a disappointing yield. If the methods recommended by the scientists are applied by those who have some knowledge of science, then great benefit can follow. But if that understanding co-operation is lacking, then frustration is added to poverty.

To raise the standard of living in any country, two things are needed: scientific knowledge, and a population sufficiently educated to understand how to apply it. Without the latter, the expected benefits will not come.

CHAPTER II

Science in the School

The place of science in the curriculum

The importance of science in the world is now recognized, and it is generally accepted that some knowledge of science is an important part of a liberal education. We are living in what is called 'the scientific age'. Any education intended to fit us for graceful and purposeful living will be grievously ill-directed if it takes no account of the intellectual climate of the present day, permeated as it is with the ideas and hopes of the scientists.

The study of the arts has its own rewards, but they are of the mind, and are slow of growth. The study of the sciences also has its rewards, and they too are partly of the mind, but much more are they practical, of immediate benefit, to be enjoyed forthwith.

The inclusion of science in the curriculum is not only justified by the tremendous influence of science upon our modern civilization. The nature of the subject makes it worthy of a place for its own sake. It provides methods which, applied to a mass of data, can extract broad generalizations, with much resulting economy of human time and thought. Within its own set limits, it exercises a creative function in drawing order out of chaos. By the stimulus it can provide to the imagination, by the precision it demands in the use of language, by the emphasis on logical order and sequence which it constantly impresses on its students, it makes a contribution to intellectual and emotional growth which cannot wisely be neglected. Half a century ago science was struggling for a place in the scheme of education. Today, there is a danger that the subject may displace some of the older, but no less valuable, educational disciplines.

The aims of science teaching

The first and obvious reason for teaching science is to give information about the world in which we live. This needs to be built up into an orderly body of knowledge, and into this system must be fitted the phenomena with which the pupil himself is familiar. He then finds himself in a world of related happenings, of fundamental and curious similarities. He discovers, for example that vibrations and movements tend to travel in waves, that living cells everywhere conform to the same pattern, and that every flower, the world over, is a variant of, even if it does not achieve, a standard arrangement. A pupil may learn of several extraordinarily different instances of resonance, but his amazement at their variety must be supplemented by appreciation of the fact that one explanation is common to all: he should understand, and be stimulated by, the idea of that one single thread woven through the whole fabric.

Probably the most important purpose of science teaching is to make the pupil aware of the methods and attitudes of scientists. He should be encouraged to endeavour consciously to apply the various disciplines in other walks of life. These disciplines demand accurate observation, the selection of relevant facts uninfluenced by prejudice, patience to carry through impartial experiments, an awareness of the possibilities of error and knowledge of the means to reduce them, an ability to estimate the value of information gained, the skill to formulate hypotheses and a willingness to test their truth. The pupil must be given every opportunity of applying these disciplines in seeking the answers to his own questions.

Thus he may come in time to possess a mind informed by a body of organized knowledge, to have his curiosity aroused, his powers of observation trained, and his judgement developed. There should be built up in him an uncompromising regard for facts as distinct from opinions, a readiness to revise theories in the light of additional knowledge, a certain air of detachment in the face of a problem, and an unwillingness to become emotionally aroused in an intellectual process. He should be prepared to keep an open mind, to reach no conclusion at all if he has inadequate information.

Practical work is essential to the main purposes of science teaching. It has, besides, a value of its own. Some people have a natural gift for devising 'gadgets', apparently being able to visualize some suitable contrivance to meet any particular mechanical need. They are quick to judge shape, size or distance, and have a 'feel' for the adjustment of mechanisms. Such gifts of improvisation, invention and manipulative skill, are the foundation upon which industrial development is built. In countries where mechanical devices are not yet in common use, the School has responsibilities for the special provision of opportunities for the development of the skills necessary in a mechanical age. The industrialization of a country cannot be based solely on the training of engineers and other experts: it must depend to a great extent on the nimble fingers and skill of the mass of the population. One of the aims of science teaching must be to help to encourage the growth of these basic skills.

In the course of his studies, a pupil should learn something of the history of man's conquest of nature. He cannot do this merely from the biographies of a few famous scientists. The work of lesser men, upon which great generalizations of science are often based, must be recognized. Something is also needed to illustrate the difficulty of original thinking, to show how even men of genius can miss what, in the light of later knowledge, seems so obvious. Topics at once suggest themselves: e.g. 'the alchemists', 'the theory of phlogiston', 'the invention of the electric lamp'. The scientist is engaged in a difficult pursuit, and success is often attained by the co-operation of many rather than through the work of single individuals. Thus the pupil may not only learn to admire the great men, but also to appreciate the efforts of others, and to be prepared, himself, to play a humble and helpful part.

To arouse a sense of wonder in a pupil is one of the most rewarding experiences a teacher can enjoy. A teacher of science has unequalled opportunities of doing this. The kind of reaction he desires most is not merely the temporary, uncritical wonder which can be produced by some shining, complicated apparatus—a wonder which can equally well be aroused by the sight of the inside of a radio set, the instrument panel of a motor-car exposed for repairs, or the projection apparatus of a visiting camera van. It is, rather, that quality of wonder only aroused when the underlying principles of an ingenious device are understood, or when the imagination is first stirred, for instance, by appreciation of the vertebrate pattern or any of nature's designs among living creatures.

The place and importance of General Science

The pupil often makes his earliest acquaintance with science under the guise of 'Nature Study'. The facts presented are those which are of immediate and *personal* interest. Questions such as these are asked: 'Where does chocolate come from, and who grows the cocoa?' 'What are the stages in the life of the caterpillar that destroys my father's crops?' 'Is it a fact that the parent birds rear their family and look after their little ones just as my father and mother look after my brothers and sisters and me?' 'What things are needed to make the plants around me grow?' During this stage in the pupil's career, one of the most important tasks the teacher has to perform is to wean him away gradually from the narrow and personal approach; it is unreasonable suddenly to restrict his curiosity to one branch of science in which he may be little interested. His study of nature needs to be extended by the development of an attitude of detachment; he must move towards the scientist's view-point. Facts about the material world in which we live are of interest in themselves, not merely because they have an immediate relation to our daily lives. The special interest in things that affect the pupil personally remains; it should remain with him all his life, but more needs to be added.

Science is a unity. We may take biology, and add chemistry, and add physics, and add the rest of the sciences, but the sum of them all does not make up what is implied in the word *science*. Science, the whole of it, is like a symphony. Each musical instrument can play a solo on its own account, but forty solo instruments, when played together, do not necessarily produce a symphony, however well each instrument may be played. So *science* is more than a collection of sciences. The one over-riding and compelling reason for teaching General Science is that a pupil shall be aware of this oneness of all scientific knowledge; or at least that he shall be given an opportunity of realizing it. Some knowledge of world history and world geography is recognized as desirable at the eleven to sixteen years' stage. The case for introducing a wide range of scientific facts is equally strong. An immense amount of valuable material, acquired in the study of one branch of science, has sometimes lain unused and unprofitable because its relevance to some other branch of science has not been realized. It is impossible to know, in the early stages, which branch of science may attract a pupil most, or, in the end perhaps, provide him with a career.

The question is often asked: 'Is it possible to provide a student with a glimpse of the vastness of the field in which scientific methods can be used with profit, and not at the same time make his acquaintance with it so superficial as to be useless, and so shallow as to provide no mental discipline?' This question is based on a misleading use of a metaphor which likens intensity of study to thickness, and breadth of study to area. The metaphor could, in fact, be used to imply an affirmative answer. Given an amount of material it is surely a fact that, spread thin and welded into a tube, it is more robust than when packed into a solid rod of the same length. A little information can be precise, there is no need for it to be vague. To understand how a machine works it is not a matter of great consequence whether the amount of material that is churned through it is large or small. So with the material upon which an understanding of science is to be based.

It has already been pointed out that the branches of science cannot be completely separated. As more attention is given to matter common to two specialist sciences, more and more names are invented to describe the area of common interest. Physical chemistry, bio-chemistry, bio-physics and electro-chemistry are some of the names which illustrate this tendency. As the interlocking and overlapping of the various sciences become more and more evident, so the reason for the study of General Science, rather than one science only, becomes more and more apparent.

Under the title General Science is developed a syllabus which seeks to provide sufficient information for the pupil to appreciate the application of scientific methods. The syllabus draws attention to the vast field in which scientists work. It also tries to present science as a whole, a vision which a pupil who has been too early restricted to one or more specialist sciences, may never see.

The content of the General Science syllabus

So vast is the field of knowledge which the modern scientist surveys that it is no small problem to decide what facts shall indeed be taught. The following points should be kept in mind:—

(*a*) We must determine what is fundamental to all the sciences, and from the abundant material available must decide what most readily provides the data upon which the more important generalizations of science can be based.

(*b*) The selection must be controlled by the aims of science teaching. There are, for instance, several ways of obtaining the formula which connects the focal length of a lens with the distances of an object and its image. It does not follow that the method which seems simplest to a mature mind is necessarily the method which the pupil will most readily understand. The question arises, 'What ideas can be assimilated by pupils at the various stages of their school careers?' Some scientific generalizations are in themselves easy to understand. They can be demonstrated by experiments within the capacity of the pupils themselves to conduct. Boyle's law and Ohm's law are examples. The tropisms of roots and shoots of living plants are similarly easy to understand and to demonstrate. Other topics are more difficult: for example, the methods by which atomic weights can be inferred from the more easily determined equivalent weights—the reasoning requires a mind much more mature than that needed to grasp Boyle's law.

The rule 'begin with what the child knows' is no less important because it has been emphasized repeatedly. A good teacher follows the instruction, in whatever form it is given: by proceeding from the known to the unknown, from the particular to the general, from the familiar to the strange, from the concrete to the abstract (and back again to the concrete), from the simple to the complex (psychologically), from the empirical to the rational.

(*c*) The material for a General Science syllabus must also be selected to match the intellectual development of the pupil. Three stages are to be noted in a child's attitude to new knowledge. At first it is easy to arouse in him a sense of wonder. The colour-changes in litmus, for instance, are a source of never-failing entertainment when an eleven-year-old boy first sees them. The sense of wonder becomes more and more critical as time goes on, but never disappears entirely, so that a good science teacher always displays a touch of 'showmanship' in his demonstrations. The second stage is one where an increasing interest is taken in the *use* of the information given. At this stage, for instance, litmus becomes of interest because, by its use, strong acids and alkalis can be neutralized to form salts; and because other indicators can be used to find out if a sample of soil is acid and whether a farmer should add lime to his land. The third and last stage is attained when the pupil feels increasingly the satisfaction of being able to arrange facts logically, and enjoys the 'discovery' of those laws after the manner of the mature scientist. It is at this stage that something of the theory of indicators may be outlined, if only a brief explanation as to why and when the commonest indicators are used.

(*d*) Students differ in temperament, and defy our attempts to classify them into neatly separate types. Some pupils enjoy learning about the mathematical laws which underlie physical and chemical phenomena. They enjoy working out calculations based upon them. Some derive deep satisfaction, and gain a more fundamental understanding, from a simple mathematical relationship between variables, as in Boyle's and Ohm's laws. They have sometimes been deprived of this experience by the omission of quantitative calculations from a General Science syllabus. To others, no less intelligent, the descriptive information, equally precise, which belongs more especially to the biological sciences, appeals strongly. It may be true that, on the whole, boys tend to prefer the logical and mathematical aspects of science, and girls the utilitarian and descriptive aspects. As far as possible the syllabus must cater for all tastes.

(*e*) The teacher should know something of the pupil's environment, what facts he may be expected to know already, in what attitudes he has been trained. For example, it is well to know whether his background is urban or rural, whether his family are merchants or sailors, farmers or factory workers. This knowledge should influence to some extent the choice of illustrative material. If a majority of a class comes from one group, then the syllabus will require more fundamental adaptation.

(*f*) The community, because it supports a child during his years of study, has a right to voice its opinion as to what he shall be taught. The construction of a syllabus will be influenced by knowing what will be of most value to the community into which the pupil must eventually fit himself.

(*g*) The problem as to what to teach has a further complication. Some pupils will, later on, pursue advanced courses at a university, for which lessons at school are expected to be some preparation. Others, the majority, are likely to cease full-time studies earlier.

How far is it possible to devise a syllabus which will be, in its early stages at least, equally appropriate to both classes of students?

To reconcile the opposing demands of individual freedom and social order calls for statesmanship of the highest degree. Similarly, to find a syllabus capable of meeting the different requirements of the individual members of a class calls for all the wisdom and experience the science teacher possesses. There is no ideal solution: the best solution is the best compromise. There is no finality about any answer. There will be gaps which the teacher will recognize with varying degrees of regret, but this is inevitable. More than two thousand years have passed since it was claimed for one of the wisest of men that he knew everything: no one today claims to know everything about science, or even about one branch of it.

And when a syllabus has been constructed, the emphasis which any teacher will give to its parts will be affected, and rightly (though it is hoped within the bounds of discretion), by the particular enthusiasms of the teacher himself. For experience shows that it is enthusiasm which makes the most lasting impression on a pupil, and is therefore the teacher's most valuable attribute.

The relation of General Science to other subjects in the curriculum

(*a*) The skills and attitudes developed in one subject are not automatically applied by a pupil to other subjects. It is the business of all teachers to suggest to pupils that to arrange work logically, to describe exactly, to be neat and tidy, and so on, are valuable accomplishments at all times; as valuable in the study of language and composition as in science, valuable at home as well as at school.

(*b*) In some schools a system of marks is used to classify the abilities or progress of children, and promotions from class to class may depend in part on these marks. When this is the case, co-operation is needed between teachers in the matter of maximum marks allotted to different subjects, and the proportion of marks allotted to theoretical and practical work. Pupils are sensitive to suspected inequality in the credit which equal diligence and ability gain in the different subjects. Teachers are apt to underestimate or even ignore these youthful, often suppressed, feelings of injustice. Teachers have invented these systems of assessment. On teachers falls the responsibility of seeing not only that justice is done, but that it can be seen to be done.

(*c*) When the various aspects of a topic are dealt with at about the same time by different teachers, from the point of view of their own subjects, the impact of these lessons on the pupil is much greater than when they are separated by a long interval. Teachers must strive for some degree of correlation. This correlation is in addition to the need, within the subject of General Science itself, to relate different aspects of the same subject. It is helpful to mention events in world history which coincide with famous discoveries. A reference to Lavoisier and the French Revolution will fix the time of the collapse of the phlogiston theory firmly in the mind. The scientific leadership gained by Germany in the early years of this century in the discovery of practicable means of nitrogen fixation, and her monopoly of the manufacture of many scientific instruments, was a factor in the timing of her declaration of war in 1914. A historical chart on the walls of a room where perhaps history is specially taught, can be constructed with a column devoted to scientific development. A list giving some dates of outstanding scientific interest will be found in Appendix A, page 283.

The teacher of language and composition might occasionally be asked to look at a set of science essays, or descriptive accounts of experiments, so that both teachers and taught feel that there is co-operation in the development of conciseness and precision in writing. The language teacher may be willing to suggest essays on subjects of scientific interest as a change from essays of the more usual kind. It should be remembered that some science books, for example on natural history and biography, are also valuable contributions to literature.

But it is in co-operation with teachers of mathematics and geography and geology that the possibility of correlation arises most frequently. At a conference between the teachers of these subjects and the teachers of General Science, there should be consideration of such matters as the following. Can simple equations in a mathematics lesson be illustrated by experimental data obtained in a science lesson on specific heat, latent heat, or the simple properties of lenses, for instance? Can the mathematician deal with inverse ratio just before the science teacher discusses Boyle's law?—or would the former like to use laboratory results to illustrate his lesson? Can the two teachers decide upon the most interesting way of dealing with graphs, which often provide an excellent means of representing scientific facts? For example, the distances travelled by a stone falling under gravity, and the route taken through the air by a cricket ball or the water from a fire-hydrant, may be connected with the graph of a simple quadratic. Can the measurement of angles and the drawing of triangles in geometry be coupled with the study of the mariner's compass and the use of the prismatic compass in science? Can the syllabuses in mathematics and science be adjusted to make all this possible, and, if so, at what stage in the courses?

When does the geography teacher wish to deal with climate? Can it be arranged so that he does this after the science teacher has given his lessons on air pressure, atmospheric humidity and their measurement, and on heat and the construction and use of thermometers? Topics such as the relationships between plant and animal distribution and the density and activities of the human population, and the occurrence and composition of chalk hills and coral reefs, concern both geographer and scientist. Can geography lessons be fitted in after those in science which deal with the lower forms of life and the composition of chalk? Even if collaboration with the other teachers may prove impossible in detail, the General Science teacher, giving his lesson on the preparation of carbon dioxide, must draw attention to the fact that chalk is of equal and common interest in chemistry, biology, geology and geography. Coral, sea-shells, limestone and other forms of chalk [1] are all used as sources of lime. Coral and chalk have been formed from living creatures, and the process continues today. Countless millions of the skeletons of these creatures have been gradually compressed, thus forming great reefs, mountain ranges and vast geological measures. The action of acids, or heat, can release the carbon dioxide taken in by the creatures millions of years ago. In mentioning such points the teacher not only forges links between the various branches of Science but provides material which may fire the imagination of his pupils.

(*d*) The headmaster must decide how much school time shall be given to General Science. Scientific knowledge is based upon experiment. If science is to be taught at all, then practical work by the

[1] *Note*—Blackboard 'chalk' is *not* calcium carbonate.

pupil, as well as demonstration by the teacher, is essential. To omit the practical work from science teaching is as unsound in educational practice as to omit paying proper attention to foundations in building practice. But unfortunately, practical work takes up much valuable time—an amount of time which may, to a teacher of history for example, seem disproportionate. A science teacher is sometimes made conscious that his demand for pupils' time for adequate practical work, in addition to ordinary teaching time, has a cold reception from the majority of his colleagues. Yet the science teacher needs, on his side, to recognize the value of the studies in which his colleagues are engaged. When he is given, for his subject, almost double the time that any other teacher gets (commonly about six periods of forty minutes each, each week), he must utilize that time to the best advantage. Of all lessons his should be the most carefully prepared and the most efficiently organized.

The relation of General Science to the specialized sciences

It must be emphasized that all pupils need to be provided with a wide survey of the whole field of scientific endeavour. Logic and experience can confirm the need for junior students of science to pursue some appropriately designed course of General Science. But it is inevitable that the time comes when a pupil who remains at school long enough must begin to make a special study of one or more of the branches into which scientific inquiry is divided. This is demanded, both by the vastness of the field surveyed by science, and by the need for the pupil eventually to render some particular service to the community. At what age must the student begin to specialize? At what stage must General Science give place to one or more of the usual list: botany, zoology, chemistry, physics, geology?

There is no clear-cut answer. Various factors have to be taken into account, and the best time for the change will be found by balancing these against one another and reaching a reasonable compromise. The following questions should be considered:

(*a*) What are the intellectual qualities of the student? Dull, average, or superior? The intelligence of the student is likely to affect the length of his full-time education. The science course appropriate to those who will end their formal education at fourteen is not the same

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as is suitable for those who continue in school until eighteen. It may differ markedly from what is suitable for those who will follow an advanced course in a university. Of the latter there will be a difference in the course at school according to whether the subsequent university course is mainly in arts or mainly in science. In general the more intelligent the student the earlier is he able to grasp general ideas, and so the earlier can he afford to specialize, provided, of course, that he has not omitted a General Science course of, say, three years. Of the two classes of university students, those who will follow an arts course can with profit continue with a General Science course at school longer than those who will follow a science course.

(*b*) What equipment is available in the school? The cost, per pupil, of equipment adequate for teaching General Science is less than the cost of equipment necessary for teaching a specialized science. Unless the teacher is a person of infinite resource and unfailing imagination, attempts to teach more advanced work with very limited apparatus are likely to prove not merely fruitless, but even harmful. To endeavour to 'learn science' without an adequate experimental background misleads a student about the groundwork upon which the scientists base their conclusions.

(*c*) What teachers are available? Whereas in some countries it is easier to find a specialist than a teacher prepared to teach the elements of various branches of science, in other places the supply of specialist teachers may be small. (Some teachers are reluctant to give a General Science course merely because they have specialized at the advanced level in just one of the sciences. This suggests that they are not prepared to extend their own knowledge, thus offending against the very spirit of inquiry which should inspire them and be encouraged in their pupils.) And teachers are not equally good. Some are mere reciters of notes, others mere purveyors of facts. The privilege of training a pupil and watching him pass through the early and more important stages of his development is too often lost sight of in the anxiety to gain the unwarranted prestige which sometimes attaches to the teacher of specialist subjects at advanced level. For by the time the pupil has arrived at the advanced stage in his studies his emotional attitudes are fixed, and his further development is rather in extent than in kind. It is the early stages of learning that are critical. There is an element of truth in the provocative statement that 'any fool can teach the fifth form'. (By the 'fifth form' must be understood a class which has been at a secondary school for about four years and is at the stage when it takes an external school-leaving-certificate examination.)

(*d*) What is the size of the school? Where the annual intake of a school is one new class each year the problem of providing general or specialist teaching may differ greatly from the problem which faces a school where there is an intake of perhaps three classes a year. In the latter a change from General Science to specialist sciences need not take place simultaneously in parallel classes.

(*e*) Has the school any established reputation? A tradition of success in the teaching of certain subjects is not lightly to be thrown away. Yet the dead hand of past triumphs may have in the end a depressing effect upon future successes. Past traditions should not count for too much when the constant aim should be the benefit of the pupils. It must always be remembered that the school is there for the child, not the other way round.

One definite recommendation may be made. Where a child begins his school career at the age of six, then between the ages of eleven and fourteen, and for a period of not less than three years, he should follow a General Science course. Whether he should continue that course for one more, or for two more years, must be decided in the light of the foregoing considerations.

CHAPTER III

The Selection of Subject-Matter

The basic principles of selection

It has been shown in the previous chapter that the following points should be taken into account when determining the content of a General Science syllabus. The material must be:—

(*a*) fundamental;
(*b*) related to the needs of the community;
(*c*) related to the subsequent career of the pupil;
(*d*) suitable for teaching—
    (i) appropriate to the pupil's intellectual development, temperament, needs and interests;
    (ii) related to the pupil's environment.

(*a*) *The argument from history*—A developing embryo passes through stages which can be considered to represent the history of its race. Similarly, the interests of the developing child appear to follow the order of the earliest concerns of human beings. Human knowledge can be divided primarily into two parts: what we know about OURSELVES and about THE WORLD AROUND US. The world around us is made up of the EARTH and the UNIVERSE. On the EARTH there are two kinds of things, LIVING THINGS and NON-LIVING THINGS. (1) Man's first interest was in living things, and he asked questions, probably in this order: 'What about them?' 'How can I use them?' 'How can I control them?' 'How can I develop them?' Thus *biology* is a fundamental study. When man appeared on this Earth he shared it more intimately with other animals than he does now. If he were to survive, a man had to know something about their appearance and their habits. He then learned to make use of them for food, and later to control them; and so some animals became domesticated. Then man learnt to develop them, to breed more useful and profitable types. A similar sequence is found in the story of man's connexion with agriculture. First he learnt to recognize plants, he used some for food and some for medicine. Then he cultivated them, and finally developed varieties which are an improvement on those found wild. Thus, the living things to be studied first, in a General Science course, should be those which are most closely associated with our everyday life. (2) Man early learnt to recognize the heavenly bodies. He made systematic observations, and later was able to put them to practical use; for by them he knew when seed-time had come, or when the rains might be expected. Thus *astronomy*, the study of the universe, is also seen to be fundamental. (3) *Chemistry* had its beginnings during the Iron and Bronze Ages, when man learnt to win metals from their ores. Although the knowledge that men gained was empirical, discovered probably by chance, it was none the less valuable. So chemistry has its place in the course. (4) In the process of gaining more and more control over his surroundings, man invented various mechanical devices: the wheel, the lever, the inclined plane. Thus began the study of *mechanics*. The argument from history establishes biology, astronomy, chemistry and mechanics as being of fundamental importance.

Science: pure or applied?—It has been claimed that it is the recognition of a need which gives the spur to the search for wider knowledge. It is suggested not merely that 'necessity is the mother of invention', but that 'technology is the father of learning'. It is claimed, on the other hand, that without the pursuit of knowledge for its own sake, many fundamental discoveries, only later put to practical use, will never be made. It is pointed out, for example, that it was through the pursuit of 'pure' knowledge that the vacuum flask was invented; that low frequency electro-magnetic waves were discovered before Marconi thought of using them in 'wireless', and that the public demand for radio communication arose from the results of 'pure' research. Here 'pure' science came before 'applied' science, and the 'knowledge' before the 'need'. When undue attention is paid to either of these points of view, science makes but halting progress. Surely the two claims merit equal consideration. The pursuit of truth, and the social urge which drives men to seek knowledge for a particular purpose, are like the steps which men take when they walk naturally. First, one foot is in front, then the other. A General Science course must provide a body of material knowledge of value to the community, and also offer a mental discipline. It must illustrate both attitudes.

Facts of everyday experience—One object of a General Science course is to introduce children to the general underlying principles which scientists have so far discovered in the universe; and evidence for the existence of these principles can be found in numerous phenomena. The examples chosen to illustrate the principles should be those with which the children are most familiar. The principles are like pegs upon which the examples are hung. The children will find some examples more interesting than others. Some facts are of personal concern to them: the working of their own bodies; their recreations; the activities of older members of their own family; matters of common experience, seen or used daily. The more common the fact, the greater is its claim to inclusion in the syllabus.

General Science and the traditional science 'subjects'—Whatever items are chosen for inclusion, they will, later on, be taken up in more detail in the study of the specialized branches of science. They will re-appear under the headings physics, mechanics, chemistry, geology, astronomy, botany, zoology, and their sub-divisions. But the whole point of General Science is that, at the start, these divisions are ignored. If they are introduced at all it is as a matter of convenience and not as a result of necessity or the arbitrary selection of some branch of science. The General Science approach is to put aside all these divisions, to begin from fundamentals, decide what is needed, and then to organize, in some rational manner, the material selected.

The matter selected for inclusion in the syllabus must be assembled in reasonably large groupings. The gravest and most damaging criticism of a General Science syllabus is that it is 'all bits and pieces'. The 'snippets' must fit into some larger synthesis, which must become obvious to the pupil as soon as possible.

Principles and their illustration—In constructing a syllabus, one method is to divide the task among two groups of teachers. One group must think out the fundamental principles of science which it is desirable for a child to know. The other group must make a list of the facts which are likely to be of interest to a pupil, with which he may be familiar, or of which he should be made aware. The principles selected are then illustrated by the facts chosen.

The inclusion of 'astronomy'—It has already been suggested that, because of its early interest to man, astronomy has a fundamental claim to inclusion in a General Science course. The claim is too frequently ignored. In a General Science course a student is expected to become acquainted with things so small and near that they can only be seen through a microscope. Why, then, neglect the examination of objects which are vast but happen to be so far away that the aid of a telescope is desirable? The majestic regularity of the apparent motion of the heavenly bodies; the problems connected with planetary motion, once so baffling but now simply explained; the awe-inspiring phenomena of solar and lunar eclipses; the beauty and the cause of the changing seasons: all these provide material for profitable study. Wherever men sail the seas, or fly in the air, the study of astronomy is essential as the basis of the art of navigation. Those who have to think of economy in the school may be reminded that even a telescope is not a necessity for the study of the heavenly bodies, as is proved by the discoveries made by the ancient Egyptians and Greeks. Further, the heavenly apparatus does not deteriorate with the years, nor does its upkeep present any earthly difficulty. Moreover, observations can be made more readily and regularly by schoolchildren in the tropics than elsewhere because there are no short nights, and most of the visible stars can be seen during the course of a clear night. At the equator the path of a star across the heavens is a semi-circle, and the movement appears to be vertical at rising and setting; and, again, the bearing of the point of rising or setting, from due east or due west, is the same as the declination given in a star catalogue. These two statements remain approximately correct within the tropical zone. Thus the identification of stars and constellations becomes comparatively easier the nearer the observer is to the equator.

Appendix B (i), page 287, gives a list of the brightest stars, with the names of the constellations in which they appear and a note of the time of the year when each can best be seen.

The inclusion of 'mechanics'—One argument on educational grounds for increased attention to mechanics lies in the fact that the subject opens up a wide range of experience, and provides practical, concrete material on which routine exercises in calculation can be based.

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It has indeed been suggested that mechanics belongs more to the teacher of mathematics than to the teacher of science. But, as the subject matter arises most easily from a study of physics, it is better for it to be introduced by the science teacher, and for advanced work in the subject to be made the responsibility of the mathematics teacher.

There are other, and more practical, reasons why mechanics should be given an adequate place in the science syllabus. The increasing mechanization of labour all over the world makes its inclusion essential. More and more people are being required to look after more and more machines. Increase the number of those who understand the fundamental arrangements of mechanical devices, and there will be a vast decrease in the annual wear and tear of cars, tractors, and machinery of all kinds, with corresponding benefit to the world's economy. For machines are too often in the hands of, and under the administrative control of, those with no knowledge of their construction and reasonable use. Further, a knowledge of elementary mechanics gives the intending purchaser some basis upon which to judge the relative claims of advertisers, and to estimate the efficiency of a machine for its purpose.

The subject matter of mechanics provides a body of knowledge which is readily organized around the basic idea of 'work', so providing a teaching 'unit' which is logical and has immediate contact with the pupil's environment.

The inclusion of 'sound'—Music makes a universal appeal. There can be scarcely any part of the world which is without its indigenous variety. This branch of science deals with the nature of sounds and draws attention to the simple arithmetic of harmony and the many kinds of musical instruments. It can hardly fail to be of interest.

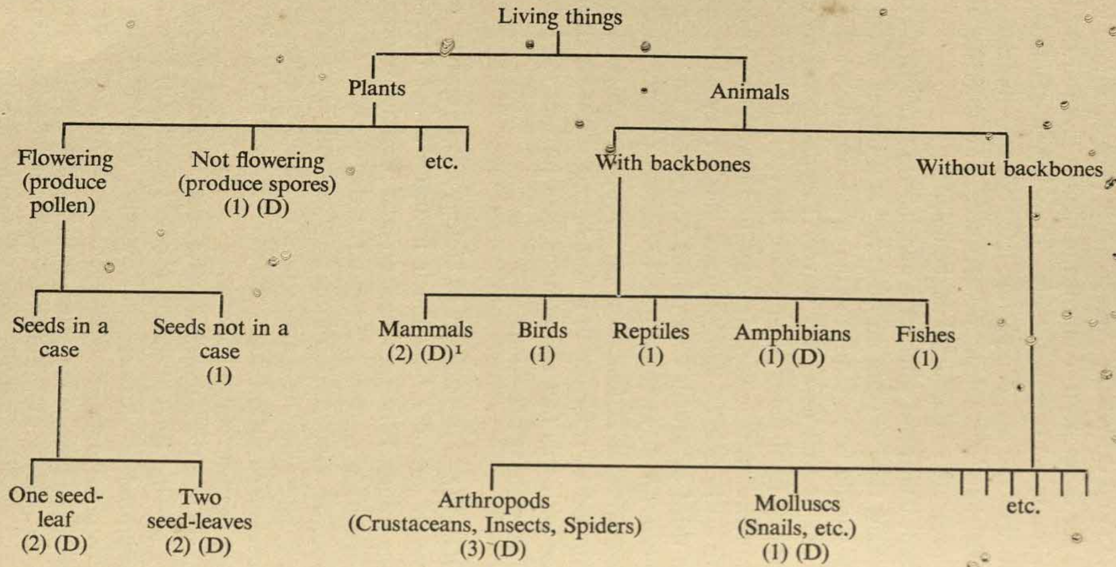
A knowledge of the characteristics of wave motion is valuable not only in the study of sound, but of light and all electro-magnetic vibrations including X-rays and radio waves, the action of springs, the movement of pendulums, water waves, the output of electric generators, the behaviour of cranks in every machine where a circular motion is changed to a to-and-fro movement or vice versa. Sound probably provides the most suitable and convenient introduction to the whole vast subject. For sound waves are of comparatively small frequency, and the wave-lengths of musical notes can be readily shown, as the ways of measuring them are well within the comprehension and skill of the average pupil. (The equation $v = n\lambda$ can be used, for example, to confirm the figures given in the issues of radio programmes.) It is useful, also, to include a simple account of the structure of the ear, comparing, later on, the vibration of the ear-drum with that in a telephone ear-piece, and referring to the variation of pressure in the liquid in the cochlea.

The apparent change of pitch of a constant note, from an object approaching and then passing an observer, is a matter of common experience. It should be remembered that the same effect holds good for light waves as well as sound waves. The displacement of the spectrum lines of light from fast-moving heavenly bodies has provided astronomers with a vast amount of information about the universe. The arithmetic of this 'Doppler effect' may be more than a boy in the third or fourth year of his course can be expected to understand, but no pupil should be permitted to pass through a science course without at least hearing about it. The phenomenon is best understood by referring to it first during the study of sound. Acquaintance with this fact alone more than justifies the inclusion of an elementary study of sound.

How much biology?—The teacher of biology has to exercise careful judgement when deciding how much to teach about the various kinds of living things. If he goes into too much descriptive detail, the mass of information confuses the pupil. If he neglects to contrast type with type, or omits to point out how different species perform similar tasks, then what he teaches fails to hang together and becomes a disorganized collection of bits and pieces. This is a criticism often directed against 'Nature Study'.

There are two questions which may be asked about any organism: (i) according to what general plan is it constructed? (ii) how far are its parts organized to deal specifically with different tasks? The teacher has to point out the main types of animals and plants, and describe the various functions which living organisms perform. The species he will choose for illustrative material will depend on the flora and fauna of his neighbourhood, for he should, of course, choose local species.

The chart in Figure 2, page 30, shows a simple classification. The



[1] One small mammal and Man.

FIGURE 2.—A chart: indicating a method of selection of biological examples

numbers in brackets represent the number of species of each group which should be brought deliberately to the attention of a class. The letter (D) indicates that the examination of one species should be carried out in some detail.

To this selection is usually added an account of the simplest of known microscopic organisms: a one-celled animal, a rather more complex animal, a microscopic plant, a yeast and a mould.

There is now sufficient material to illustrate the change: from simple-celled organisms, exercising all the functions associated with a living creature, to the most complex arrangements found in mammals, where different tasks are undertaken by special cells developed for the purpose. The information can be revised and linked together by considering such topics as 'methods of reproduction', 'sensitivity to light', 'the body plan', 'digestion', 'how animals move', and so on.

(*b*) *The needs of the community*—Far too many 'educated' youths are forsaking their villages to find employment in towns. The resulting break-down of family and tribal sanctions has had a most demoralizing effect. What is still worse is that many who, if their education had been wisely directed, might have done much to raise the standard of life in the rural areas in which they were born, have treated the problems of rural life with contempt. They show no intention of returning to live among those more primitive surroundings where their gifts and training are most needed.

There are reasons for this deplorable state of affairs. One is the materialism of the age in which we now live. But the influence of the type of education provided in the past, ill adapted as it was to the needs of the community, has played a sinister part. The educated members of a particular community are often acquainted only with the type of education they themselves were given. They assume that the training they received cannot be improved. The mistakes of the past have been perpetuated because teachers, in their turn, have developed a vested interest in maintaining the only system with which they are acquainted. The community as a whole, respecting the judgements of these 'educated' members, has demanded the continuance of an outworn system. The blind have followed blind leaders.

The teaching of General Science can play a part in altering this state of affairs where it exists, and ensuring that it does not arise elsewhere. It should take into account the immediate needs of the community. It should include instruction in elementary hygiene, and discussion of the principles underlying the recommendations, in this field, of the government departments concerned. It should give an insight into the fundamentals of agriculture and the beneficent and profitable changes which the application of science can bring to the cultivator. It should provide a background upon which various social practices can be judged, and encourage the laying aside of some old-established but misguided habits and customs.

If some disease in an economic crop threatens the welfare of a community, that subject should be included in the syllabus, and the reasons that lie behind the recommended treatment should be explained. If some social habit or taboo deprives the land of the manure which should be available for agriculture, the matter should be discussed during the course. In the primary schools only the simple facts need be considered. In the secondary schools the reasons must be understood.

The science teacher who has opened the eyes of his pupils to the inexhaustible wonders of the countryside, and has given them the instruction and practical experience by which its economic resources can be increased and developed, has done more for the community than one who has merely led his pupils through some old academic discipline.

(*c*) *The subsequent career of the pupil*—A General Science course for a secondary school is not intended deliberately to provide for vocational training. It may well be, of course, that the student will develop an interest in some elementary branch of science and will wish to make a special study of it later on. A syllabus biased to provide training in some means of livelihood, in which pupils can engage as soon as they leave school, is suitable for technical and vocational schools. The General Science syllabus in a secondary school which is neither technical nor vocational should be so designed that the pupil, when he leaves school, will be a useful citizen, adaptable, with a wide range of interests and sympathies. Such training will provide that foundation of knowledge and experience which will enable him to benefit from more advanced and specialized courses.

(*d*.i) *The needs and interests of young people*—The selection of material for a General Science syllabus, as indeed for any other subject, is affected by the intellectual development, the sex, the temperament, and the environment of the pupils (Chapter II, pages 16–17). It has already been pointed out that facts of everyday experience are likely to stimulate interest. It has been suggested that a large amount of illustrative material is available in every locality if the teacher will but search for it. A few more observations may be made here.

Young people respond to striking contrasts. Comparisons between past and present, for instance, are often of great interest. A picture of a modern laboratory can be put side by side with a copy of an old print showing an alchemist's den. A picture of a seventeenth-century scientist, with curled and powdered wig, may be contrasted with the modern idea of a chemist, sleek in white overalls. Similarly, the first steam engines can be contrasted with modern locomotives, and the first 'flying machines' with modern aeroplanes. Contrasts in scale are also effective: e.g. a diagram showing calcium carbonate heated in a hard glass test-tube, and one of a modern continuous-burning vertical lime-kiln. The teacher will notice that such examples illustrate a teaching method, as well as providing teaching material.

Young people are more interested in the latest devices and discoveries of science than in prolonged discussion of past triumphs. A regard for the past, an interest in the stages by which present knowledge has been patiently built up, is not a youthful development. If the subject is 'oxidation', the work of Priestley and Lavoisier has to be considered. But the interest soon wanes if the historical aspect is too long drawn out. A mature mind is left unsatisfied by the historical snippets which are all that children aged 11–13 can absorb. But the pace must not be forced. Historical references therefore need to be short and should consist mainly of biographical sketches. As a stimulus to the development of the 'historical perspective' an occasional allusion to anniversaries of great discoveries, or to a date associated with a famous scientist, can be made, and used as the starting-point of a lesson. A list of such dates is given in Appendix A, page 283.

Because of this interest in the latest inventions, rather than in the discoveries of long ago, new material should be selected to illustrate old facts. Thus the cine-projector has replaced the old-fashioned 'magic lantern' and, as a lesson topic, now arouses more interest, though the main optical properties of both are the same. Young people are always keenly interested in what they see 'in the paper'. A national or local newspaper very often contains an article on some scientific subject, or carries an advertisement referring to some new device or product. If it is something within the comprehension of a class, this is a good reason for referring to the matter during the course of an appropriate lesson, or even for devoting a part or the whole of a lesson to the subject.

(*d*.ii) *The selection of local examples* — No text-book can contain all the examples of local phenomena, or all the local examples of general principles. The skilled teacher will find for himself, and encourage his classes to find, these local and particular examples. The use of known, locally collected material as a starting-point helps to arouse or maintain interest. The known facts can then lead to the teaching of other facts more remote from the experience of the pupil, and possibly more important. By association with the familiar, the new and unfamiliar is the more easily remembered. The historian has for reference, among other things, local ruins, statues, places of historical interest, the contents of local museums. The teacher of geography can use, in the same way, the weather and the physical features of the school surroundings. The teacher of General Science also has local material in plenty if he will but look.

While many examples of scientific interest are mentioned in any text-book of General Science, no one author is aware, for example, of all the applications of the principles of mechanics in use in the world, nor is any text-book large enough to contain them. It is the proper and profitable task of the teacher of General Science to supplement the text-book used by his class with illustrative examples which he himself has collected or noted in the areas from which his pupils come. Let us take, for example, methods of irrigation.

In N. Ceylon and S. India, water is raised, by means of 'wellsweeps', from shallow wells, and allowed to run in small irrigation channels. A long tapering pole, which acts as a lever, is balanced just above its centre of gravity (see Figure 3). The pivot is raised above the ground, passing through the top of two vertical posts. From the thinner end of the pole hangs a bucket which dips into the well. The bucket is full of water, a man stands on the pole at the balance point, then walks along the pole away from the bucket. Soon his weight causes the thick end of the pole to move downwards. See-saw-like, the thin end of the pole rises and brings up the bucket of water with it. When the bucket is emptied into the irrigation channel the man walks upwards to the point of balance, the thin end of the pole dips downwards, the bucket fills, and the man once more walks away from the pivot, up the slope of the pole, and the process begins all over again. Here is a local example which provides all the necessary data for a very effective lesson on *moments* and *work*.

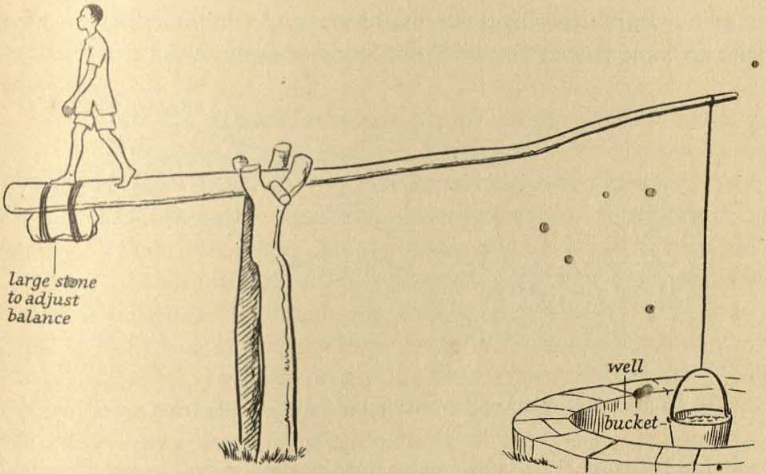


FIGURE 3.—A 'well-sweep'

A simpler device, using a long pole as lever, and called a 'shadoof', is used in N. India. 'Treadmills', in which the application of a moment is continuous, are sometimes used in India, China and Japan.

In S. India and other places, water is often raised from a well in a bucket attached to a rope passing over a pulley, which is fixed over and above the edge of the well (see Figure 4). The rope is pulled by a pair of oxen, which walk down a slope—the inclined plane making the work easier. Camels are similarly employed in some parts of N. Africa. (Another use of the inclined plane is seen when logs, weighing many tons, are raised on to timber lorries in the W. African forests. The logs are pulled up over long stout poles placed at a slight incline from the top of the lorry to the ground.)

Such local examples are excellent, and, because they are so familiar in the areas mentioned, are far more educative than most text-book illustrations. Other instances of the use of mechanical devices come to mind. Primitive oil presses use leverage to obtain sufficient pressure to squeeze out the oil from seeds; supple sticks are used as springs for traps, or to close gates automatically; cranks are attached to potters' wheels; devices are in use for applying brakes to bullock carts. In different parts of the world various devices are used for winding silk from the cocoons of silk worms; an equally great variety of methods, yet all illustrating the same principle, is in use for spinning thread for net-making, yarn for weaving, and fibre for rope-making. A bicycle, common in most parts of the world, is a veritable battery of devices which illustrate mechanical principles. The brake connexions and cranks provide examples of levers; there are the means for making use of friction (brakes) and for reducing it (ball bearings, and the use of oil and grease); the free wheel is an example of the use of ratchet and pawl; springs are used in tension and compression; there is an air valve; there are devices for locking nuts. The velocity ratio of the whole machine can be calculated

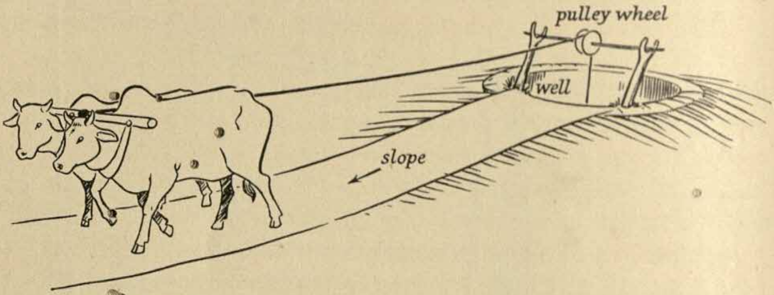


FIGURE 4.—Another method of raising water from a well

by measuring the length of the pedal crank, the radius of the back wheel, and counting the cogs on driving sprocket and free wheel.

The biologist has at his disposal, everywhere, many examples which can amplify, or be used as a substitute for, those to be found in General Science text-books. It would be difficult to name an inhabited area of the world (and in uninhabited areas there are no children to teach) where there are no representatives of numerous families of birds and animals; and often the more remote the area, the more varied its flora, with plants of many families and a wide range of leaves and flowers and habit. In the absence of the customary geraniums, beans, peas, etc., of the text-books, local weeds can be grown in pots for experiments. They are usually robust and survive neglect.

Local methods of bread-making may be studied. What is used in place of 'brewers' yeast' obtained from beer vats in temperate climates? Does it contain, or consist similarly of, the tiny living plants that decompose sugar with the formation of alcohol and carbon dioxide? In some places certain species of palm trees are 'tapped' for their sweet sap. This ferments rapidly and is therefore mixed in to leaven the dough, the bubbles of gas making the bread 'rise'. (Baking kills the yeast plants, drives off the alcohol, and leaves the bread full of 'air-holes' caused by the escaping carbon dioxide.) Such material should be examined under the microscope. Its action should be demonstrated in a test-tube fitted with cork and delivery-tube. When the warm mixture of sugar and fermenting agent 'works', the carbon dioxide should be identified by passage into lime-water. It should also be shown that boiling stops the reaction—the importance of a control experiment not being forgotten.

The teacher can look for variants in the methods of carrying out agricultural and horticultural operations. For example, there are various ways of 'layering'. The art of layering consists in causing roots to grow along a thin branch while the branch is still attached to the parent bush or tree. In some areas moss is tied around the branch, in others vegetable fibre such as raffia, or coir fibre from the coconut husk, is used. The material is kept watered until rootlets have developed. Sometimes the branch is staked down to the ground, or it may be buried for some of its length under the soil. When the rootlets have developed the branch is cut off and planted, and the roots are all ready and can begin to function at once. In this way plants can be propagated without the risks which attend such methods as growing them from cuttings, when the planted stick may dry and die before roots have time to develop.

In dry areas there are methods of irrigation to note; in wet areas there are the methods of drainage which prevent the soil becoming water-logged; in hilly areas of storms and heavy rains there are methods of contour trenching which help to conserve the soil and prevent erosion—all these are illustrations of the way in which man seeks to control his environment.

The examples which a teacher will collect, or note, will frequently be appropriate to one or other of two categories. They will have a rural background; or they will have an urban background. The teacher whose lessons are illustrated by the same examples, whether he is teaching urban or rural children, is not efficient. There is a wealth of examples to be found in an area which is developing industrially, and many everyday experiences of the pupils may be turned to good use by the teacher of General Science. Interest in the facts which a study of geology reveals will probably be intensified in areas producing mineral oils. The distillation of crude oil can lead to a discussion of boiling points, distillation in general, fractional distillation, the effect of pressure on boiling point, distillation under reduced pressure, and thus to that article found the world over, the tin of evaporated milk! Acquaintance with petroleum and its uses may lead in another direction, to a discussion of combustion and its products, of water and carbon dioxide as evidence of the presence of hydrogen and carbon. This in turn may lead to a study of the effects and transmission of heat.

In areas producing coal, a similar introduction to the facts of geology is possible. The subsequent study of the use of coal can lead on to a discussion of oxidation and reduction, and to the part played by coal in the production of iron from its ores.

It is only reasonable to expect that samples of minerals mined locally should be on the shelves of every school laboratory. Such minerals as limestone, bauxite, manganese dioxide (pyrolusite), as well as various mineral salts, which have properties simple to demonstrate, should be dealt with in the course.

When a teacher of General Science moves into a new school or goes to a new area, one of his most urgent and profitable tasks is to have a watchful eye for new illustrative material for his lessons. One of the claims made to justify the inclusion of General Science in the curriculum is that through it a spirit of watchfulness and inqury is developed in the pupil. It is of the utmost importance that the teacher himself should show the same spirit. Without it he may stand in front of a class and talk, but he will fail to achieve his main purpose, and may even do more harm than good.

The place of the text-book

It can be assumed that the person who has written a text-book has chosen his material according to a set plan and purpose. He has visualized a certain type of school and pupil, the background and the need. He has decided upon the information he thinks it most important to impart, and has in mind the attitudes he hopes will be encouraged by the use of the book. A text-book, by another author, on the same subject and for pupils of the same age and background, often differs considerably, especially in the selection of material. Yet underlying both books is a recognition of the same fundamental principles, and a desire to encourage the same attitudes. It is not surprising, then, how widely text-books may differ when written for different age-groups and for pupils with different backgrounds.

The teacher must ask the following questions when he tries to decide whether a text-book is suitable for a class:

For what age-group is the book written?
What background knowledge does the author assume?
What attitudes is he trying to encourage?

The needs of a class are never exactly met by any text-book. It is the teacher's business to find the one which appears to be the most suitable. Because a text-book is used in one school is no argument that it should be used for a class of the same grade in another school. All depends on the similarity, or otherwise, of the schools and the background of their pupils. Having found the most suitable text-book the teacher will have to supplement some parts and ignore others, fitting his lessons to his classes.

The attitude of teachers to text-books varies from one of complete page-by-page reliance to one of contempt for all text-books. The first attitude is due to ignorance and lack of initiative, the second to pride. Both are regrettable. The function of a text-book is to supplement the teacher's lessons, to save the pupil from wasting long hours in mechanical note-taking, and to make sure that he has a definite amount of information brought to his notice. The teacher who relies entirely on a book is confusing teaching with cramming. When a text-book is not used, the pupil has to rely upon written notes. These are often scrappy and mis-spelt, sometimes lacking logical order. They are usually inadequately illustrated. The notes may be still more inadequate when pupils are absent from class for a time, or when the teacher is unable to cover the desired syllabus. Between the two extremes a reasonable compromise is both possible and desirable.

When a text-book of General Science, restricted in size, is in use over a wide geographical area, then the material it contains should deal with generalities rather than particulars. For instance, if the text-book is dealing with pollination, then the diagram showing the growth of the pollen tube down to the ovary should be a generalized one. The pupil, however, will have examined a local flower with a hand lens, and will have made a sketch of the flower in his notebook. The teacher will draw on the blackboard an enlarged diagram of the stigma, style and ovary, showing the route taken by the pollen tube. This diagram the pupil will copy. In this way the text-book will illustrate the general arrangement, but the pupil's note-book will contain a detailed account of a particular local species.

CHAPTER IV

The Arrangement of the Syllabus

There are many ways in which the material selected for a General Science syllabus may be arranged. So true is this that it is the arrangement, rather than the content, about which teachers of General Science find agreement most difficult. Material for the syllabus may be arranged thus:

(*a*) in the order of its discovery;

(*b*) according to some logical order, e.g. that of each separate specialized branch of science;

(*c*) by grouping around some central theme, such as:

- (i) a main principle of science;
- (ii) phenomena which are of immediate and local interest to the pupil;

(*d*) according to the mental and emotional age of the pupil.

In addition to these possibilities, and frequently forgotten in academic discussions on the subject, are arrangements:

(*e*) to suit the teaching accommodation provided by the school;

(*f*) according to the capacities and preferences of the available school staff.

It must be emphasized here that these possible arrangements of subject matter are not mutually exclusive. They may all influence, in varying degrees, the final order and groupings in the syllabus.

(*a*) *The historical order*—As has already been mentioned, pre-adolescent children do not usually appreciate historical sequence. Yet the latter, when material is being arranged, may be as useful as the logical sequence, which, indeed, it sometimes closely follows. Lessons on bacteria, methods of sterilization, and the use of disinfectants, can be linked together through the names of Leeuwenhoek, Pasteur and Lister. Other things being equal, the study of levers should come before the learning of facts about a pendulum. The observation of nature occupied man's attention before the systematic study of what we now call chemistry. Astronomy was an organized science before geology. On the grounds of history there is ample basis for the study of 'inorganic' before 'organic' chemistry, although man's early discovery of fermentation establishes a claim for the inclusion in the syllabus of an account of the preparation and properties of alcohol. An objective and critical account of the effects of alcohol on the human body has an equal claim.

(*b*) *The logical order*—In every syllabus, however constructed, the pupil must accept, for the time being, certain things on the authority of his teacher or text-book. The fact that exhaled air contains carbon dioxide (shown by the readiness with which it turns lime-water milky) can be taught before carbon dioxide has been isolated and its numerous properties demonstrated. Facts which a student must learn may be put into three categories:

(i) those demonstrated at the time of presentation;

(ii) those to be accepted for a time, but to be demonstrated later;

(iii) those to be taken for granted on the authority of teacher or text-book.

Group (i) presents no difficulty. When the teacher comes to group (ii) he should make clear that certain facts are being accepted, and if he promises to demonstrate them later, then he should be careful to keep his promise. As for group (iii) every organized body of knowledge, science no less than other subjects, has its own axioms. In order to make progress in any study, these may be used; but in the interest of truth their temporary status should be made clear.

Deciding upon the logical order is not so easy as might be expected, for there are many possible arrangements, all equally logical. It may be that the historical order is also the logical order. On the other hand some later generalization or simplification may provide the best starting point for the study of the subject. The facts usually associated with the study of chemistry may be taken as an example. Chemists divide the matter of which the world is made into two kinds, elements and compounds. Mixtures form a third group, composed of the other two. A logical system could begin with the study of all the known elements, passing on to all the known binary compounds, then to more complex compounds, and so on. A famous catalogue of chemical compounds does, indeed, follow this order. Another sequence starts from the clue provided by the periodic table, following the chemistry of the elements in the order of their increasing atomic weights,[1] dealing with their compounds on the way, and pausing for a long time over carbon and the 'organic' compounds. The elements could also be studied in the groups which the periodic table reveals, and to which meaning has been given by modern theories of the structure of the atom. (Such an arrangement is usual in advanced text-books of chemistry.) Another scheme might have as a basis the well-known division of elements into metals and non-metals, the elements of each group being taken, with their compounds, in the order either of their atomic weights or of their discovery.

The study of living things could be arranged in many ways, each quite logical. There are arrangements, according to structural pattern, following the accepted plan of phyla and orders. Equally intelligible arrangements might select material according to function. For example, the process of digestion or reproduction, or the reaction of the organism to some stimulus, could be followed through many types. Alternatively, the amoeba could be a starting point, followed by examples of the various orders, in increasing complexity, taking all the outstanding characteristics of living things as exhibited by each organism in turn.

But even the most logical arrangements are found, on examination, to involve a certain amount of arbitrary adjustment of detail. Of examples which are used to illustrate principles, there are some which can best be used after other examples have been explained. It is better to learn about the movement of liquids up and down the stems or trunks of plants after osmosis and capillarity have been discussed, unless the liquid movements themselves are used as a starting-off ground for the discussion of osmosis and capillarity.

It is possible to take a principle of science and pursue it, as it were, through its various applications. Gravity controls the swing of a pendulum and determines the acceleration of a falling body; it also affects the direction of growth of plants and is relevant to the study of the skeletal structure of animals. The inverse square law has its application to the intensity of illumination of a surface by a source of light; it is relevant to an understanding of the size of a lens of a camera and the time of exposure of a film; the strength of a magnet is calculated on the assumption that the law is equally applicable to magnetic fields. However great the determination to follow a straightforward logical sequence, it is almost impossible to avoid an interrupted and zig-zag course.

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[1] The increasing order of *atomic numbers* is the correct statement, but the atomic weights were the basis of the first periodic tables.

When logic has been pursued as far as possible there is a sense of something harsh and austere about the arrangement. What is being framed is a syllabus for teaching, something for the growing mind of a child, and this fact must be kept constantly in view. The *characteristics of the pupil* must be considered as carefully as the *logic of the science.* Fortunately, as we have seen, there are many variants, equally logical, in the arrangement of scientific knowledge. Considering the needs of the child first, and then fitting into the syllabus the material suitable for each stage of the child's development, the logic of science is allowed to exert a proper, but not disproportionate, influence. The resulting syllabus may not be as 'tidy' as one based upon pure logic, but the arrangement may be far more effective in stimulating those very attitudes and activities which it is the main purpose of science teaching to develop.

(*c*) *Grouping of material round a central theme*—The spokes of a wheel may be arranged end to end, stretching out into a straight or zig-zag line. They may also be attached to the hub of a wheel and radiate from it. So does the method of presentation which aims at a logical sequence differ from the 'project' or 'unit' method. When a fact is presented to us we tend to remember similar facts, or facts which have become connected with it in our minds for some reason or other. We notice something, we read a paragraph in a journal, or hear a conversation about a subject. We then seem to meet references to the same subject with quite surprising frequency. This is not because the subject has suddenly become of popular interest; it is because we are now alert to notice what otherwise we should have ignored. Our interest, thus aroused, spreads to matters connected with the original subject. This fact of association gives the clue for a method of arranging a syllabus, at least for the more elementary classes. When connected facts are grouped around one central theme, a 'project' or 'unit' may be developed.

(i) *Grouping round a scientific principle*—The central theme for a project may be some matter of scientific interest, a scientific principle, a scientific theory, or the measurement of a physical quantity. Some examples have been given above of the way in which a scientific principle, such as 'gravity' or 'the inverse-square law', can be logically pursued, but this is not quite the same approach. The whole of mechanics can be organized around the idea of 'work'. Around the equivalence of the various forms of energy, including chemical energy, all the data about animal and vegetable metabolism, the calorific value of foods, the maintenance of body temperature, and so on, could be collected. Around the idea of wave-motion could be grouped the study of sound, the measurement of frequency, the facts of resonance, the characteristics of musical notes, the speed of light and the rest of the electro-magnetic spectrum, the 'tuning in' to a radio broadcast, etc. A profitable series of lessons could be based on the measurement of temperature. A class may be led to consider the extraordinary ramifications of the vertebrate pattern among living creatures, or to study an environmental influence such as the weather. Biological themes might include the interdependence of animals and plants, or the adaptation of creatures to their environment. The comparative values of various topics must be considered, with regard to their scientific importance as well as the practical value of the information to be gleaned from them. It must be decided whether or not pursuit of these topics will result in the development of desirable attitudes and skills on the part of the pupils.

(ii) *Subjects of immediate interest to pupils*—In the place of various principles of science as central themes, topics likely to be of special interest to children may be selected, perhaps because of their local connexions or because they happen to be prominent in the news. The 'discovery' of scientific principles or generalizations arises in the course of the study. It is claimed for this method that examples may be drawn from a wider field and that the relationships of the various branches of science are made more apparent. A topic which takes the form of a question is likely to arouse more interest in a pupil than one in the form of a plain statement.

Around the topic 'What happens when things burn?' may be collected the chemistry of oxidation, the physics of heat and its transference, the botany of plant respiration, the zoology of animal, including human, respiration. The topic may lead to a further collection of associated material: to food and diet, to vitamins and catalysts, to various important catalytic processes such as the manufacture of margarine and artificial fertilizers. Oxidation and respiration may be connected with the functions of the blood, the heart, and thus with valves, pumps, and so on.

In a country where hydro-electric power is being developed, or where large irrigation schemes are in progress, there are, ready to hand, themes of local and at the same time scientific interest. In dealing with the former the geographer begins with climate, rainfall, and physical features. An estimate of the catchment area provides an opportunity for the calculation of the approximate area of irregular figures. There follow subjects of considerable scientific interest, such as the use of water power, dynamos and power transmission, and the uses to which cheap electric current may be put in developing a country's resources. Such a scheme is worked out in more detail in Chapter VI. The bewildering variety of ways in which a topic may be developed forms a practical difficulty when arranging a syllabus by this method. Questions arise such as: Shall 'refraction' be connected with a discussion of the various properties of water, or shall it follow a discussion on reflection of light which itself has arisen from a discussion on the properties of metals? Shall it be connected with a topic such as 'wave motion' or be attached to the topic 'how light travels'? There is no final answer. Every syllabus is to some extent a compromise, but every effort should be directed towards producing one as suitable as possible for the particular pupils and teacher who are to use it.

(*d*) *The child's stage of development*—Those who have observed the free activities of children have seen how, in the playground, one game may be played to the exclusion of all others. This continues for some weeks perhaps. Then the popular game gives place to another. Children cannot keep their attention fixed on one thing for long. The arrangement of subject matter in small groups is therefore an adaptation to the way a young pupil's mind works, in recognition of his inability to maintain sustained interest. The wide variety of items in a General Science syllabus gives great scope for a variety of projects. In the earlier stages in particular the teacher must organize his lessons and practical work so that facts are understood and results are obtained quickly, before interest has waned and boredom taken its place. At this stage a syllabus made up of shorter topics than those which pure logic would require can still provide any mental discipline that is required. To force upon a child a logic which it is quite beyond his powers to appreciate, may even develop a dislike for the subject, so hindering the process of learning. Of course there is much to be said for giving children opportunities for learning to 'concentrate', for pursuing a subject with logic and attention. They should often enjoy the satisfaction that comes to a person who, having disciplined himself to follow a certain course, and having completed it, can say to himself 'Good, I have finished that'. As pupils mature they are able to sustain interest over a longer period, and indeed need to be trained to do so. It is then that more comprehensive projects, occupying maybe a matter of weeks, or a whole term, can be arranged. Still later in the course, minds are more developed and capable of appreciating the discipline that a logical order of study can provide. Then is the time to let a collection of projects give place to the more traditional arrangement of subject matter.

The unity of knowledge is amply illustrated by the possibility of starting with any one topic, for example, 'the human body', and eventually including every known principle of science. The same end could be achieved by starting with 'the earth on which we live', or, for that matter, with 'water', or even 'the internal combustion engine'. Such arrangements, however, are very strained and artificial. A very large table can be made to balance on one leg, but its equilibrium is unstable. So it is with a huge syllabus starting from one topic. It is better to break it down into smaller topics, to 'stop and re-start'. The topic has the obvious advantage of arousing more interest on the part of the pupil. The interest must not be lost in the boredom of pursuing paths too devious to follow easily.

To the question 'What is the ideal syllabus?' there is no real answer. The best syllabus is the best compromise between conflicting desirables.

One compromise may be exploited in the construction of a General Science syllabus. The study of biology requires a less rigid logic than the study of the physical sciences. Principles and examples which are usually considered to belong to physics and chemistry can first be arranged so that material which illustrates principles common to both is kept together. Biological illustrations may then be fitted in afterwards where appropriate. In so far as some biological studies can only be profitably undertaken at certain seasons of the year, it is better to attach the contribution of biology to the General Science curriculum rather loosely, through projects that are more self-contained. This is not to suggest that the contribution of biology is less important than the contribution made to the syllabus by physics, or astronomy, or mechanics; it merely suggests that biological material is more amenable to varying arrangements.

A method of compiling a syllabus

One way of building up a syllabus for General Science in which the 'topic' or 'project' or 'unit' method of presentation is mainly used is this. Three sets of cards are made. The largest cards are about 6 inches × 3 inches and are of one colour. The smaller cards are about 3 inches × 1 inch and are of two other colours. On each large card is written one theme or topic for inclusion in the syllabus. On each of the smaller cards of one colour is written an example, of general or local interest, associated with the physical sciences. On each of the smaller cards of the second colour is written an example which might be included for its general or local biological importance. The large cards are then laid down in order, those with the topics which can be most readily understood, or, which are of most immediate interest, being placed first; those whose subjects seem more difficult, or which refer to matter more remote from the pupils' experience, being placed last. By each of the large cards is grouped the cards giving examples drawn from the non-biological sciences. Then the cards naming the biological examples are added. Thus all the material for the syllabus is grouped round the main themes.

It is now that the experience and judgement of the teacher are likely to be most severely tested. The card relating to one topic is chosen, together with its attendant cards naming the examples. The latter are set out in some logical or psychological order, so that the sequence of the examples becomes as evident as possible. The biological examples are placed in the most appropriate places. Other groups of cards are then treated similarly. In the course of making the arrangements there will be many transfers from one group to another, and there will be changes in the order in which the topics are treated. Eventually the compiler of the syllabus must have the courage to call a halt to the shuffling. The total material must then be cut down until it represents what it is possible to do in the school term in the time allotted to the subject.

A skeleton syllabus—A typical example, given in Appendix C, page 289, contains the material that might be studied in a *four-year* course of General Science, with suggestions for a *fifth* year (assuming that the pupil has not commenced a separate course in one or more of the specialized branches of science). Such a scheme can be nothing more than an example, requiring adjustment and adaptation in any particular area, even in a particular school.

It does, however, suggest the sort of order in which material may be presented, except that the later sections (biology) must be fitted in when times, seasons, and conditions are most suitable and convenient.

Teachers will note that the topics 'water', 'air', and 'carbon dioxide,' provide a foundation of scientific knowledge, the subsequent subjects being arranged increasingly on more traditional lines. The method of treatment of many items in the syllabus is discussed, generally or in detail, throughout this book.

CHAPTER V

The Approach to Science Teaching

Varieties of method

When the teacher has decided what should be taught and why, and has the aims of science teaching clearly in his mind, he has yet to give his lessons. His task is to teach so that, in due course, the aims of the course may be achieved. Each separate purpose may demand a different method. In the course of a few months a teacher may use them all. He may lecture, demonstrate, organize laboratory work for individuals or groups; he may encourage the formation of societies and clubs, provide films, lead an excursion, set examination papers with questions of various types, recommend additional reading, turn a class into a 'brains trust' or into a committee to arrange an exhibition, and so on. Whatever the methods, the ultimate aim must be an understanding of Science. Ways and means for encouraging the desirable attitudes and skills are discussed in this chapter.

Repetition (*short range*)—Pupils do not comprehend everything at once. For example, it may be a matter of weeks before the significance of 'density' is fully appreciated. During this time the determination of density by various methods is continued. Each determination introduces the same idea—weight in relation to volume. Eventually the pupil will understand that density is a measurable attribute of all substances, and will be able to make deductions as to weight, volume and density from relevant data. Even so, tests must be given at intervals until the idea is firmly established in his mind.

Repetition (*long range*)—The extent to which any question may be studied depends on such factors as the stage of mental development of a class, the background knowledge which it already possesses, and the time at the teacher's disposal. As these factors vary, it is usual for a subject to arise more than once during a school science course. At each stage more information is gained and broader generalizations are developed or confirmed. It is not reasonable to expect a pupil, on first acquaintance with respiration in animals, to dissect a mammalian heart, or on first acquaintance with lenses to become familiar with formulae relating the position of object and image with focal length. Such topics require gradual development at various stages in the course.

Solving problems

Knowledge of scientific facts is valuable, but it is even more valuable to be able to apply that knowledge to the solution of practical and everyday problems. (Problems are of many different kinds, and the word is used here in its widest sense: it does *not* refer merely to questions requiring numerical answers.) The sooner a pupil learns how to search for the answers to his own and others' questions the better. In the process facts will be made known, scientific methods used, attitudes confirmed and interests aroused.

Before leading a class towards the solution of a problem, it is wise to consider whether the problem is set out in the best possible way. It must be stated clearly in words which the class understands, and it should be restricted in scope. If it is in any way ambiguous, or covers too much ground, it should be broken up into simpler parts. The methods which are applied must also be either familiar to the pupils or be well within the range of their understanding. It should be possible to reach definite conclusions by use of available apparatus in suitably simple experiments. For instance, the question 'How does a mariner's compass work?' is not so simple as at first appears. Is the need merely to discover how it is used, or how it is suspended, or which way it points? Or is it necessary to go into the question of magnetism more deeply? If the latter, then attention must be paid to the common properties of all magnets, from magnetic iron ore onwards. In other words the question must be broken down, so that its ambiguities may be removed. The following questions might be suggested:—

What happens when a magnet swings freely?
Do all magnets behave in the same way?
In which direction does a freely swinging magnet point?
What is the best method of suspending a compass needle?
Is it best for a compass needle to swing freely over a graduated

circle, or for the card on which the latter is drawn to be attached to the needle and swing with it?

Will tilting affect the needle? Is there any device for maintaining its horizontal position?

From this series of simpler questions the original question is made more amenable to experimental investigation. If the class is sufficiently aroused, the properties of magnets in general will be interesting enough to demand formal attention. A class of appropriate grade may well go on to inquire what other direction-finding apparatus is available and be made acquainted with the gyro compass or the earth-inductor compass.

There is a fairly well defined sequence of operations in the solution of a problem. First the problem has, as it were, to be brought out into the open. Then some sort of stimulus, perhaps some matter that is uppermost in the minds of the pupils or of the community, or some question carried over from another lesson, is needed for a suitable beginning. Pupils must be aware that there really is a problem, and that its solution is desirable and will bring a sense of satisfaction. This awareness may be stimulated by a news item, a pupil's or teacher's question, or a well selected demonstration. In the absence of any better beginning the teacher may have to state baldly the subject he has chosen, but the most profitable method is to deal with a problem which has already been raised. A short reminder of the circumstances which led to the raising of the problem is all that may be necessary by way of introduction.

Next, the problem should be examined and, if necessary, broken down into simpler portions, as described above.

When the problem has been sorted out, and its parts clearly stated, the next process is to collect the information which will lead to its solution. This may come through deliberately planned experiments, or it may be obtained by searching reference books or magazines, from interviews with people possessing the necessary knowledge, from facts observed during excursions, or from any other available sources.

The information must then be sorted out to determine what is relevant and reliable. From this the next step is to propose a possible answer or reason.

The scientist is not yet content. Any hypothesis must be subjected to further trial, and another series of tests may be designed to find out whether it can be confirmed. For, if a hypothesis is true, it will hold good for facts and events other than those which led to its propounding. Even then the process is not quite complete, and a final task may be to discover whether the fact or explanation obtained has any practical application. If it has, then this in itself gives to scientific methods an impressive value in the eyes of a class, and to produce this result is one of the major aims of science teaching.

Two problems follow, and ways in which they may be attempted are suggested. They are examples of a line of approach to be followed whenever possible.

Example A—Transpiration—What happens to the water used by plants?

(*a*) *Understanding the problem*—When a plant, growing in a pot, is placed under a dry bell-jar, the inside of the jar soon becomes misty. —It appears that water is given off by the plant. Where can this water have come from?—The soil. How does the water get into the soil?—Water is poured into it. Does the weather make any difference to the amount of watering necessary?—More is needed during dry and hot weather. When flowers and leafy branches are kept in a jar of water, more water must be added from time to time. Does the water in the jar evaporate straight into the air?—Or does it pass through the flowers and leaves first? During hot sunshine, or in a strong dry wind, leaves go limp and wilt.—Why is this?

Thus might be launched a lesson on transpiration in plants. How did these questions first arise? What started them off? What trigger of interest was released to raise them? The teacher has not begun by saying, 'Today we will study the phenomenon of transpiration in plants.' Something much more subtle has occurred. Somebody has noticed, possibly from experience in the school garden, that plants need more water in hot weather, or has pointed out the limpness of leaves in the sun and wind, or has realized that a jar of flowers and leaves lacks water. The teacher may ask himself, 'But how can I be sure that these questions will be asked at the right time, so that my scheme of work can go along as planned?' There is no certain answer, no rule to be observed. It may be suggested, however, (i) that perhaps the teacher's scheme could be improved by revision; (ii) that it is more important that scientific facts and ideas should be taught than that they should be taught in an unalterable sequence; (iii) that, although the appropriate opening questions may not come from the class spontaneously, the imaginative and skilful teacher can usually achieve the same effect by judicious prompting; (iv) that, in fact, pupils being suggestible, it is one of the recognized teaching skills to lead them to ask the desired questions and to leave them feeling that the initiative has been theirs.

(*b*) *Analysis of the problem*—Has any question been asked which can be simply answered by an experiment? Yes, that concerning flowers and leaves in a pot of water. Can the pupils formulate the question, the method, and the controls and variables? Is it a fact that water is quickly lost? Some flowers and leaves are placed in a jar of water and the fall of the water level is noted. Is this due to the flowers and leaves? May it not be due to ordinary evaporation? What experiment can be devised to find out? The usual scientific method can be used: *two* jars of water, of the same size and shape are used. The same volume of water is put into each, and the leaves and flowers into one only. Both jars are left together in the same place under the same conditions. After a day any difference between the levels of the water remaining in the jars is noted.

Is there any means of finding out at what rate water is given off by plants, and what differences are made by temperature, wind, etc.? What exactly should be done?—Is it possible to collect and weigh the moisture coming from a plant in a given time? Can any pupil suggest how the moisture might be collected? If it is difficult to measure the moisture from the leaves, is it possible to measure what goes into the leaves? By what route does it 'go in'?—Through the stem. Is it possible to measure what goes up through the stem? How?—By cutting the stem and inserting some measuring device through which the upward-moving water must pass. A small leafy branch is obtained from the school garden, and the end put quickly under water. The simplest of all potometers is then fitted up, and the whole apparatus is filled with water. The stem is cut rather shorter, this time while the end is held under water, and by means of a piece of rubber tubing an air-tight joint is made between the stem and the narrow tube into which it is put (Figure 5 (*a*)). The water level in the side tube is seen to move down gradually, showing that water from the apparatus is moving out, and the only way out is through the leaves of the branch.

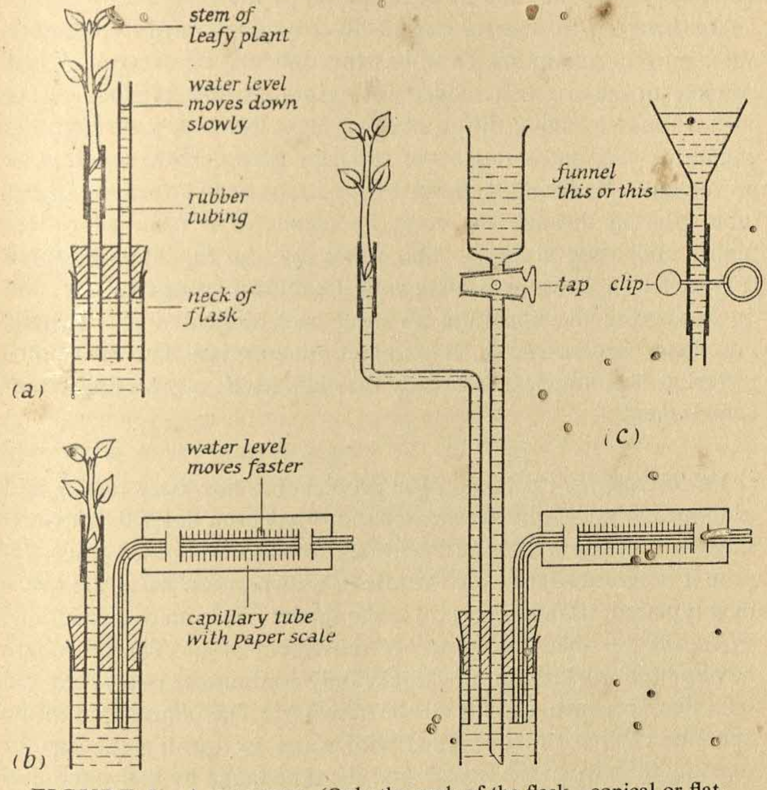

FIGURE 5.—A potometer. (Only the neck of the flask—conical or flat-bottomed—is shown. The whole apparatus must be full of water)
(*a*) First stage. (*b*) Second stage. (*c*) Third stage

Are there any criticisms of the apparatus?—The movement of the water in the side tube is very slow. How can it be made to appear to move faster?—By making the tube narrower. A capillary tube of about 1 mm. bore is fitted into the side tube, either vertically or horizontally. This works admirably, for the movement of the water along the tube can be seen at once. But how far does it move in a given time?—The tube must be graduated. How?—By fastening a ruler behind it; or by making marks along it at equal distances apart; or by fitting a piece of ruled writing paper behind it (Figure 5 (*b*)). (In the latter case several parallel slits are cut in the strip, which may then slide along the tube through the loops thus formed.)

Are there any further criticisms?—It is very awkward to put more water into the apparatus. How may this difficulty be overcome? Is it possible to make another opening?—Another hole is made in the cork, to take a funnel. But water may now flow freely through the apparatus and out through the capillary tube.—How can this be prevented?—By fitting the funnel with a tap; or by attaching it to a tube, passing through the cork, by means of a piece of rubber tubing and using a clip, so that water may be run in as required (Figure 5 (*c*)). Thus, by dealing with the difficulties one by one, and by improving the apparatus to meet each difficulty, a 'Farmer's potometer' is constructed. It is in fact not so much 'Farmer's potometer' as a potometer devised by the class itself: a more important achievement.

(*c*) *Collecting the evidence*—The problem has now been raised, and examined, and an appropriate apparatus has been devised. The next stage is to decide what experiments are to be carried out. Let us suppose it is agreed to measure the rate of transpiration when the specimen is placed: (i) in the sun; (ii) in the shade; (iii) in an open window, where there is shade but plenty of movement of air. The procedure having been worked out, it will take only a minute or two to cut and fix a new specimen, should this be necessary. The plant is put in the sun, the capillary tube is filled with water by turning the tap, or opening the clip, of the funnel, and the time taken by the water level in the tube to move through, say, 5 line divisions, is noted. The apparatus is then placed in a closed room, and the time taken by the water level to move through the same number of divisions is noted. The experiment is repeated exactly with the apparatus in the draught at an open window. The results are noted; for example:—

Plant in:	*Time in minutes*
sunshine	5
closed room	15
draught of air	9

The results of the experiment with the two jars of water are also available: the loss of water is far more rapid from the jar containing flowers and leaves than by evaporation from that containing water alone.

(*d*) *Interpreting the evidence*—What does the experiment with the two jars show?—That water seems to be drawn from the jar by the leaves and dissipated into the air. What does the experiment with the potometer show?—That water is given up by leaves exposed to the sun more rapidly than by leaves kept in the shade; and also that wind causes the leaves to lose water more rapidly than still air.

(*e*) *Conclusions*—Plants lose water through their leaves. The water passes up the stem of the plant (having entered through the roots). The rate of loss depends on the temperature and the amount of wind. In what sort of country would a great deal of water be passed into the air?—In forest, jungle, and areas of dense bush. Rainfall and vegetation maps should then be compared.—It will be seen that the afforested areas are areas of highest rainfall. Why is this?—The mass of leaves allows so much moisture to pass into the air that it quickly becomes saturated and there is therefore more likelihood of rain falling. Or perhaps vegetation grows fastest where there is plenty of rain? Can both suggestions be true?—Yes, they can.

(*f*) *Practical applications*—Is it possible to alter the climate of an area by planting forests?—Yes, assuming that the young trees thrive. Are there areas in the world where tree-planting is done deliberately in an attempt to influence the climate?—Yes, forestry departments often have this in view when areas proposed for development are being considered.

(*g*) *Other facts explained*—Although people usually walk in the shade along a forest path, and the temperature is lower than in the full glare of the sun, yet they find the atmosphere 'heavy'. This is due partly to their being sheltered from any wind, but more especially to the high humidity caused by the moisture passed into the air by the dense vegetation. Outside the forest the air may be hotter, but it is less humid and not so still.

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The temperature in the forest is lower than outside. Is this because of the shade alone?—No. Why?—Because when a liquid evaporates it requires heat, becoming cooler and thus cooling the surface upon which it rests. (The connexion between evaporation and latent heat may be revised, if suitable, at this point; or it may be kept as one of the opening questions in subsequent lessons on latent heat.)

If we lie down on a pile of green leaves cut from the forest we notice that they seem cool to the touch even on a hot day. How does the movement of water through plants help them on very hot days? —It keeps the leaves cool and prevents them from becoming dry and shrivelled.

Example B—Rusting—Why does iron sheet, used for roofs, rust and have to be replaced?

(*a*) *Sensing the problem* — Here is a practical problem that affects the owners of houses and other buildings. It is serious, because a great deal of money is spent, all over the world, on roofing materials. The money needed for frequent replacements could often be used for other important purposes.

Considerable damage may be done when roofs leak; things inside the buildings may be ruined by rain, and the walls may remain wet for long periods and finally break down. Rusty iron roofs give an unsightly appearance to a town or village, and visitors get a poor impression of the inhabitants. Interest in the problem may thus be aroused from either the practical or the aesthetic point of view, preferably from both.

(*b*) *Analysis of the problem* — The next stage is to sort out the factors which may be involved; to break down the problem into smaller parts, which, when solved, may provide an answer to the whole. The kinds of questions which may now be asked are:—

(i) Does constant wet weather or constant dry weather affect the rate of rusting?

(ii) Do iron roofs rust faster in hot than in cold places?

(iii) Are there roofs made of other metals, and do these rust and need replacing?

(iv) How does the rust differ from the original iron sheet?

(v) Iron roofs are sometimes painted. Does this serve any useful purpose, or is it merely to improve the appearance?

(vi) Where does rusting first begin on an iron sheet?

(*c*) *Collecting the evidence*—The questions which have arisen must now be examined and the answers sought by systematic inquiry. There is no limit to the range over which it is possible to search for evidence. Experience in the laboratory, the rest of the school, the school compound, the home, the village, or more distant places, may all yield useful suggestions. Pupils who have read widely, or have developed good habits of observation, have an immense advantage over their fellows in the value of the contribution they can make to this stage of the lesson.

The laboratory is a place where, on a small scale and under controlled conditions, happenings in the world outside the school may be repeated. A full-size iron roofing sheet is too large and expensive to bring into a laboratory, but a small piece, either cut from a larger sheet or found discarded on some building site, will serve the purpose.

A new piece of iron sheet, examined closely, will be seen to have a surface patterned with bright streaks, apparently crystals. Scraping with a sharp instrument seems to expose a different metal surface underneath. The partly scraped specimen should be handed around the class for examination, because here may lie an important clue to the understanding of the whole problem.

Taking the questions raised, one at a time but not necessarily in the order in which they were asked, action might be as follows:—

(v)—A pupil is selected to ask a local builder, or an engineer, whose business it is to put up or maintain roofs of this type, whether, in his opinion, painting lengthens the life of iron sheets. This is a task to be carried out during out-of-school hours, not in class time.

Perhaps a member of the class knows of two roofs, erected at about the same time, one painted and the other not, and may be asked to find out whether there is any evidence that one lasts longer than the other.

(i)—Is any evidence available? Does any pupil know two areas of different climate well enough to be able to venture a useful opinion? If not, does any pupil know of an iron sheet upon which water constantly drips, for example from an overflow pipe, and is there any reason to think that this rusts faster than might be expected? Where is this example to be found?—others should be able to examine it. If there seem to be no convenient examples which can help to answer the question, is it possible to arrange for some samples of sheet iron to be kept wet, and others dry, so that any differences in rate of rusting may be noted?

This may lead to suggestions for an experiment:—small pieces of iron sheet are placed in three test-tubes of water: (1) in the ordinary state; (2) after scraping with a sharp knife; (3) after painting.

If pupils have already learned that when water boils the dissolved air is driven out, this is the time to revise, and obtain the suggestion that three similar samples may be put into test-tubes, the water boiled, and stoppers at once employed to exclude air. The six test-tubes are then prepared and labelled.

(iii)—Does anyone in the class know of roofs made of sheets of metal other than iron?—Aluminium sheet is being increasingly used, and lead sheet has been used for the purpose for at least 2,000 years. Do these rust as fast as iron, or more slowly, or not at all? Can we find out?—Samples of the metals are required, so that a piece of aluminium and a piece of lead may be put in two test-tubes of ordinary water, and similar pieces of each in test-tubes of boiled water. The four samples are labelled and placed with the others.

Are there any other metals which might be used for roofing?—Perhaps zinc, tin, or tin sheet (the material of which the 'tins' (cans) of preserved foods are made).

Evidently a few more specimens must be added to those already set out. So pieces of zinc foil, tin foil, and 'tin' cut from an empty food container are immersed in ordinary water, and in boiled water, as in the previous cases.

(vi)—The results of the experiments should supply the answer to this question.

(ii)—Pupils cannot find out directly whether iron roofs rust faster in hot than in cold countries, and it will probably be impossible to perform suitable laboratory experiments. The class may have to wait for a lesson about the effect of temperature on the speed of reactions, or may simply have to accept the fact that chemical reactions are slower when the temperature is lower.

(iv)—Suggestions for an experiment to find the answer to this question may have to wait until the results of the others are available. If, however, from his reading a pupil is able to suggest that the difference is brought about by iron taking oxygen from the air, the usual experiment may be set up. A little water is shaken up in a long glass tube closed at one end, and poured away. Iron filings are then dusted into the tube so that they stick to the wet sides. The tube is then inverted over a beaker of water and left to stand.

(*d*) *Interpreting the evidence*—(v)—The report from the builder or civil engineer will show that painted iron roofs last longer than unpainted ones. It may also point out that roofing sheets should not be scratched, and that the number of nail-holes should be kept to the minimum.

(i)—Evidence provided by the specimens in the test-tubes may be summarized thus:—

Specimen	*Effect of ordinary water*	*Effect of boiled water*
scraped iron sheet	rusts	does not rust
plain iron sheet	rusts at the edges	does not rust
painted iron sheet	does not rust	does not rust
aluminium sheet	does not rust	does not rust
lead sheet	does not rust	does not rust
zinc foil	does not rust	does not rust
tin foil	does not rust	does not rust
'tin' sheet from food can . . .	rusts at the edges	does not rust

(vi)—Rusting begins at the cut edges.

(iv)—The iron filings rust; water rises part way up the tube and then stops at a certain level.

(*e*) *Conclusions*—The results of (i) and (iii) in respect of metals immersed in boiled water, show that it is the presence of air that promotes rusting. The results of (iv) suggest that there is a part of air, and only a part, that is concerned with rusting. The conclusion is that if air can be kept away from iron, for example by a protecting coat of some non-rusting metal (such as zinc, tin, or lead), the iron is not likely to rust. If the iron roofing sheet is scraped, or where the edge of the iron is exposed by cutting, then the iron is unprotected and rusts. Paint is also useful because it forms an airproof covering. Scratches and nail-holes should be avoided as far as possible because they damage the protecting surface and so lead to rusting. Summarizing the conclusions arrived at so far:—

The iron used for roofing is usually covered by a protective layer of rustless material. This layer appears to consist of another metal.

Painted iron does not rust.

Rusting takes place readily in the presence of water and air.

Rusting uses up a part of the air.

To prevent iron roofing from rusting it is covered with another material to keep the air away.

In the course of trying to solve a problem it is often found that other questions arise, and these must be solved in their turn before a final answer is obtained. The routine of analysing the problem, working out appropriate experiments and collecting and interpreting the evidence has to be repeated for each question.

In the example of the iron roofing sheets a further question arises: 'What is the layer of metal that covers and protects the iron?'

Apart from an analysis which is beyond the ability of a General Science class to understand at this stage, the possible answer is that it might be zinc, tin, lead or some other non-rusting metal. The teacher may then tell the class that the metal is, in fact, zinc and that the roofing sheets are usually called 'galvanized iron'. He may describe how they are made by dipping them, when perfectly clean, into a bath of molten zinc. He may also inform the class that the 'tin' (can) in which food is preserved, and in which so many other articles are packed, is, in fact, iron sheet covered with a layer of the metal tin.

Thus question, designed experiment, evidence, and information, are fused together to provide an answer to the original problem.

(*f*) *Practical applications*—The conclusions that have been drawn about the rusting of iron have many practical applications. The evidence suggests that roofing sheets should be treated carefully if they are to last; that paint over the layer of zinc gives additional protection to the surface; that sheets of metals other than iron are likely to last longer; and that there is a considerable future for the use of aluminium, which does not rust, requires no metal covering or painting, and will last for many years.

(*g*) *Subjects for further study*—Branching off from the iron roofing sheets problem there are now other problems that may be pursued further. The question (iv), 'How does the rust differ from the original iron sheet?' has not finally been disposed of. When it is placed by the side of the question 'What happens when things burn?' the similarity in the fraction of air used up in each case provides one clue to the answer. There follows a study of oxygen, and the preparation and composition of oxides, with basic and acidic oxides; and then a long series of problems comes into view.

This kind of treatment of a problem should be a regular feature of science lessons, so that pupils come to regard it as normal procedure and to adopt it as a habit.

Development of ability to think critically

The ability to think critically is essential in a scientist. There are frequent opportunities during a science course for deliberate training of pupils in this respect, as the following examples show.

(1) *Precision in definitions*—For young pupils 'definitions' must often be descriptive rather than generalized, but they should always be clear and exact. The description is usually in terms of properties and uses one particular example. For instance: 'A bottle full of mercury is much heavier than the same bottle full of water: this is due to the greater density of mercury', and 'When a vertical glass tube of narrow bore is partly immersed in water, the level rises inside the tube and remains higher than that of the water outside. This is an example of capillarity.' Such statements are correct and are satisfactory for beginners. On the other hand, to say that 'An acid turns blue litmus red' is misleading because it applies only in certain cases. Thus it leads pupils to think that it is universally true, and also to assume that all bases turn red litmus blue and that all salts are neutral. (Yet they find that even 'acid' sodium carbonate turns red litmus blue, and ferric chloride turns blue litmus red.) The mistake lies in introducing the action of an indicator. It is far better to state that

'An acid is a substance which reacts with a base to produce a salt and water', even though it is necessary to point out that 'base' and 'salt' are defined in a similar way, and that the 'definitions' therefore form a closed circle.

At a later stage more precise definitions may be expected. For instance: 'Density is the weight of unit volume of a substance. It may be measured in grams per cubic centimetre or any other convenient units of weight and volume', and 'An acid is a compound in which each molecule contains at least one hydrogen atom replaceable by a metal'.

The meaning of a word is sometimes easier to explain: e.g. 'amorphous means without definite shape; non-crystalline.' The only difficulty in a case of this sort is to keep the vocabulary within the ready comprehension of the pupil.

The precise use of words is a skill which the pupil should be encouraged to apply in all his affairs. The teacher should therefore provide many opportunities for the framing of definitions, and should help the members of his class to avoid careless and ill-considered statements. This will involve class discussion about possible ambiguities, and criticism of the proposals put forward. It is advisable to arrive as soon as possible, in appropriate cases, at a definition in terms of measurable quantities, i.e. at a mathematical statement. But this should never be attempted until the pupils are ready for it and capable of using it.

As in so many other aspects of science teaching, the chief problem will probably be to decide upon the degree of precision to be demanded at any particular stage of the course. If the finer points of a definition imply greater knowledge than pupils possess, they cannot be expected to understand it. Thus it is the teacher's duty to help them to make a definition which can be understood and accepted, but which will not prove to be false even if further knowledge should show it to be inadequate.

(2) *Control of experimental errors*—There are many occasions when the science teacher can encourage his class to consider experimental errors and methods for avoiding them. There must be constant emphasis, of course, on careful and conscientious work and the use of the best techniques, but the importance of critical thinking must

also be stressed, however indirectly. Measurements of all kinds must be made to the degree of accuracy permitted by the particular instruments employed, so the teacher must discuss, and where necessary explain, not only the correct methods of use but the reasons for them. There must be determination to reduce personal errors to a minimum.

'Constant errors' should also be mentioned when opportunity occurs. They are often linked with the separation or elimination of various factors in an experiment. One common method of procedure may be given as an example here. The speed of sound in still air can be found even when a wind is blowing. This is done by finding the speed simultaneously in two opposite directions, the mean of the two results giving the correct value. This method is often used for the readings of such instruments as magnetometers, dip-circles, theodolites, etc., and gives a check on their accuracy. It can be illustrated by the construction of a right-angle by means of a badly adjusted set-square. (In Figure 6, angles APX and BPY are drawn with the inaccurate set-square. They are therefore equal, but each is less—it might be greater—than a right-angle. Angle XPY is bisected by CP, which thus forms an exact right-angle with AB.)

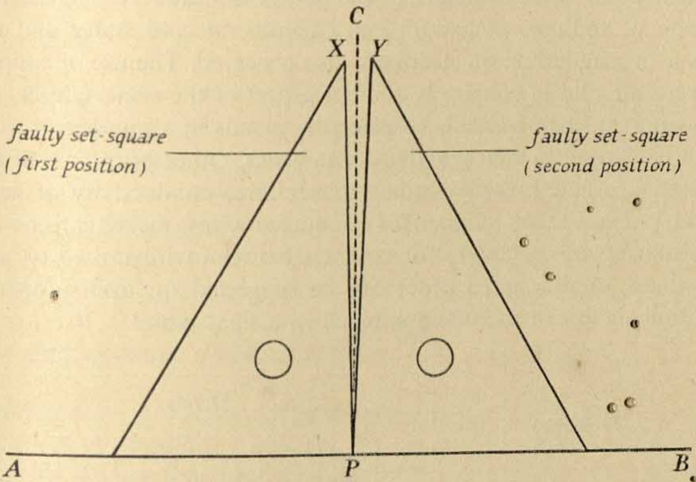

FIGURE 6.—The construction of a right-angle with a faulty set-square (an example of one method of correcting results)

(3) *Classification of facts*—The search for general principles and unknown relationships is a scientific method which involves the arrangement of known properties in some definite order. The E.M.F. series of the elements is a classic example. The method can be illustrated at General Science level by compiling a list of the properties of metals. During the course a class becomes acquainted with facts concerning the rusting of iron, the prevention of rusting by a coating of zinc (in 'galvanized' iron), or of tin (as in canned fruit 'tins'); with the electro-plating of cutlery by silver, and with chromium-plating. The resistance of various metals to the action of water is studied. The action of sodium, potassium and calcium on cold water and the effect of magnesium on steam are also observed. The use of copper, silver and gold in coinage is another aspect of the same subject. An attempt can then be made to place the metals in a numbered order approximating to their reactivity with water. Other properties of the metals are noted, for example their relative conductivity of heat, electrical resistance (copper for conductor wires, nickel-chrome for resistance wires, mercury for contacts between wires), density, and hardness. A numbered order can be suggested for each property, and all these can then be combined in a final table:

Properties	*Metals*							
	A	B	C	D	E	F	G	H
Action on water . . . . (fast to slow)	1	2	3	4	5	6	7	8
Tarnishing in air . . . . (fast to slow)	1	2	3	5	4	6	7	8
Heat conductivity . . . (bad to good)	2	1	3	4	6	5	7	8
Electrical resistance . . . (great to little)	3	2	1	6	4	5	8	7
Hardness . . . . (soft to hard)	1	2	3	7	8	5	6	4
Density . . . . (low to high)	3	1	2	6	5	4	8	7

From such a list a student should gain insight into four important matters:—

(i) The method, continually used by scientists, of trying to discover relationships between properties.

(ii) That exact correspondence between various sets of properties of a series of substances is unusual.

(iii) That generalizations are more readily deduced when such a list is prepared: for instance, in the above list it can be seen that, in general, (*a*) the denser the metal, the better it conducts heat and electricity; (*b*) the less dense the metal, the more readily does it react with water, and so on.

(iv) That generalizations make it much easier to remember the facts which they summarize.

(4) *Classification into categories*—From time to time in a science course problems arise which demand a critical estimate of alternative possibilities. For example, 'is a sponge a plant or an animal?' The teacher may recite the facts, and the pupil may learn them by heart, but this provides little scientific training. It is better to recall the facts already known, or to try to elicit from the class the characteristics of animals and plants. Then, with a knowledge of the life history of a sponge, the pupils are challenged to state in which category a sponge is best placed.

(5) *Reliability of results*—The reliability of a set of values can often be checked by plotting a graph. For example, a class may be told that the following figures were obtained in an experiment to demonstrate Boyle's law:

P (*Pressure*) lb. per sq. in.	*V* (*Volume*) c.c.
15	22·0
12	28·0
10	32·5
8	38·0
6	35·0

If these values are plotted on a graph it becomes evident that the readings P = 8 lb. per sq. in., V = 38·0 c.c., are out of keeping with the others. What should be done?—A critically minded class may suggest that the experiment should be repeated to check the original values. If repetition confirms the figures, then some hypothesis must be sought to explain it.

Desirable attitudes

Understanding of a principle—Pupils can often be helped towards full understanding by encouragement in the collection of a large number of examples with one common principle. This useful exercise not only emphasizes the particular principle, but draws attention to the number and variety of its actual and possible applications. The following are two simple illustrations of this point:—

(i) *Valves*—There are many types and numerous applications of contrivances to permit only 'one-way traffic'. (Several of the smaller kinds can be fastened to a display board, preferably with boldly drawn diagrams to show how they work.) (*a*) Air valves, e.g. of car and bicycle tyres, bellows, football and vacuum pumps. Valves for other gases and vapours, as in steam and internal combustion engines, safety valves, etc., may be studied. (*b*) Valves for liquids, e.g. in lift and force pumps, in the mammalian heart and arteries, at the outfall of sewers or drains (to prevent back-flow during floods). Water-taps—faucets—are not valves in the strict sense, although in normal usage they allow only a one-way flow. The comparison is useful for an analytical discussion. (*c*) Electrical devices, e.g. rectifiers, including radio valves, which accept alternating current (i.e. flowing in opposite directions alternately) and permit current flowing in only one direction to pass through.

(ii) *Resonance*—A rigid body has its own natural period of vibration. When it is struck gently but continuously in a manner corresponding to its natural frequency, a large vibration can be built up. For instance: (*a*) A person jumping up and down in the middle of a plank supported only at the ends causes it to vibrate strongly. (*b*) Doors or windows sometimes rattle violently when a vehicle passes. (*c*) A blow of the hand on the cement wall of a room sometimes produces an audible note. (*d*) Soldiers are ordered to 'break step' when crossing a bridge. The regular tramp of marching feet is said to have caused the breakdown of one bridge. (*e*) Earth tremors have caused the collapse of large, rigid structures, leaving humbler, and apparently less stable, buildings unaffected. 'Skyscrapers' are built in such a way that they sway gently in such conditions or even in a high wind. (*f*) A corrugated road surface can produce an unexpected shudder in a car travelling at a particular speed. This is thought to be the cause of the shattering of a large number of car windscreens on certain roads. (*g*) In old-fashioned cars the frequency of the blows on the tyres, due to road corrugation, would sometimes correspond to the natural frequency of the car's springing, and create an alarming 'wheel wobble'. (*h*) Some singers have been able to break a wine-glass by singing a particular note into it. Thus, even the slight blows of air waves, of the right frequency and continued long enough, may shatter a rigid object.[1] Hence the 'explanations' suggested in the next two examples are not impossible. (*j*) It has been suggested that the walls of Jericho collapsed owing to resonance. (*k*) A guide in the high mountains is said to have started an avalanche by whistling, causing a delicately poised block of ice to tremble and fall. (*l*) A violent wobble is sometimes imparted to a shaky table by a sewing-machine turned at a certain speed.

When practical work is supplemented by the study of such examples, the principle is not only impressed upon the memory but its significance and importance are appreciated, and the facts also are more easily remembered.

Reliance upon experience—A pupil, having completed an experiment, made a measurement, or come to some conclusion, is apt to enquire of a companion: 'What do you get?' or, lacking confidence, may ask his teacher, 'Sir, what is the right answer?' The teacher's reply should be 'What do *you* get?'—'Have you checked your methods and calculations carefully? Have you made sure that you have not made a slip, overlooked an instruction, or allowed some avoidable error to creep in?' It may be necessary to advise such a pupil to carry out the experiment a second time. When all this has been done he should be encouraged to stand by his conclusion and regard it as *his* result.

If the pupil continues to ask 'What is the right answer?' the teacher may tell him the usual value given in the text-books, adding that text-books often quote only average values, obtained from a variety of specimens. It may also be said that the values are sometimes taken from reports of scientific research, carried out by skilled experimenters in laboratories under the guidance of famous scientists, and thus may refer to particular specimens, specially selected, or purified by long and tedious methods, etc. The pupil should understand that, in view of the time and apparatus at his disposal, and in the absence of the almost unbelievable precautions that professional experimenters take, he may have done well to obtain a result within perhaps 5 per cent. of the text-book value.

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[1] When an ascending scale is sung across the mouth of a tall measuring cylinder held in the hand, at a certain moment resonance can be both heard and felt.

Honesty—The teacher's attitude must clearly show reliance upon his own results when he is doing demonstration experiments. If, as sometimes happens, a determination by the teacher provides a result far removed from what might reasonably be expected, then he must never make excuses for himself, nor try to adjust his readings or results to correspond with some theoretical value. The teacher, in all sincerity, should apologize for clumsiness or for making mistakes he could have avoided. He may well have to repeat the experiment, as a pupil might be expected to do. If a teacher frequently finds himself in this sort of difficulty, then he has probably taken insufficient care to practise his experiments before the lessons. But if the need for repetition is infrequent, far from 'losing face' with his class, he will, in the long run, gain their increased respect, and give them a very effective lesson in the importance of scientific integrity.

Scientific 'proof' of fact or statement is often impossible in elementary work, and the teacher should beware of false pretences. The experiment commonly performed to 'prove' that sound travels through air may be taken as an example. An electric bell is suspended in a bell-jar, from which the air is then withdrawn. Complete inaudibility cannot be obtained when the bell rings in this simple apparatus, although there is a very considerable reduction in the volume of sound. The teacher must be honest in stating the conclusion, which might be: 'As the air is gradually extracted, so the sound heard gets less and less. Thus it seems probable that in a perfect vacuum no sound would be heard.' He should point out that he cannot provide a rigorous proof.

Honesty must be the invariable rule, involving if necessary a confession of failure or ignorance. The teacher's example is the most important factor in the development of his pupils' appreciation and understanding of scientific methods.

Sense of responsibility—The personal responsibility of a scientist for his published results can be illustrated when a teacher takes from a class a number of their results to be included in a summary for all to copy. The name of the student responsible for each result can be added in brackets by the side of the recorded value.

Integrity—A pupil often has to rely on others for some of the experimental facts from which a conclusion is drawn. He naturally demands integrity of his fellows. In return his classmates expect him to make experiments and records which can be relied upon. By careful arrangement of practical work, a corporate sense of responsibility can be built up. The teacher may remind a class so trained that a community as a whole can only reach its highest level of development when the habits of integrity and reliability, essential in a science laboratory, are exercised in every aspect and walk of life.

Appreciations in science

Scientists are often remarkable for their tireless research and incessant probings into Nature. What provides them with the enthusiasm that marks their activities? Why do they find the study so absorbing? One purpose of teaching science is that pupils may come to understand something of this enthusiasm, to appreciate the spell cast by science over its students, and to perceive how scientists maintain, through long spells of apparently fruitless search, the conviction that it is well worth while.

It is remarkable how often people who have made valuable contributions to knowledge, when seeking to explain their inspiration, attribute success to the influence of a teacher. The enthusiasm of the teacher, much more than his knowledge, communicates itself to the pupil. Unfortunately, there are teachers who, lacking imagination and enthusiasm, merely convey information, and regard their profession solely as a means of livelihood. A teacher cannot inspire the gifts he does not possess, nor expect a pupil to follow where he does not lead. It is unfortunate that those teachers who lack the spirit which should inspire them are usually least conscious of their own condition.

Understanding of science is not developed in the absence of emotional bias. Inevitably the pupil has an emotional as well as an intellectual attitude to the subject. The two may be at variance, as when a boy is interested in science as a study, but has little respect for, or even dislikes, his teacher. An inquiring mind may be withered by a teacher's sarcasm. The satisfaction to be found in a reasoned argument may be partly frustrated by irritation, conscious or unconscious, at the incompetence of a teacher who leaves loose ends of arguments untied and allows himself to be distracted from pursuing a steady sequence of lessons. A pupil may fail to discover the purpose of his study, or it may appear to him to be remote and irrelevant, causing his interest to wane and making him indifferent. The knowledge of 'how the body works' may not have been presented in the form 'how *my* body works'. Study may have been centred on 'a plant' not '*my* plant' or '*our* plant'. It may be that the material is not suited to his particular stage of emotional development, or is remote from his own experience, or that the teacher has failed to make clear the important connexions with familiar things or facts already known. The teacher sometimes mistakenly assumes that necessary discipline may be resented, that a pupil desires his studies to be made easy, and that, if they are not, he will lose interest. The reverse is quite as likely to be true. If the purpose of the study is seen to be worth while, interest is created and thrives on the discipline demanded.

Such attitudes as these, in the minds of pupils, form the background against which the teacher must play his part. But in many instances there comes to the pupil a moment of insight, when that which was remote becomes real and immediate, a moment of illumination when truth and knowledge for their own sake become supremely worth while. Then exploration of the unknown becomes a passion rather than a task, offering a challenge which must be met, and the mechanical processes of scientific investigation are recognized as merely ingenious methods for revealing the incomparable wonders of Nature. It is not within the power of even the best of teachers to guarantee that any particular pupil will experience this 'enlightenment', which does not accompany pride but is given only to the humble. But every teacher can work and scheme for it; even hope and pray for it. He can do no more, he should do no less.

In order that the pupil may enjoy the satisfaction of an illuminating experience, the teacher himself must be constantly aware of the real meaning of his subject. For example, to the question 'Why teach biology?' there are numerous answers: to improve the methods of agriculture and animal husbandry; to raise the standard of hygiene, both public and private, and to reduce sickness and disease; to give pupils an understanding of their environment and increase their ability to control it; to enable them to appreciate scientific methods, especially the use of control experiments, and to train them to use them; to encourage their powers of observation; to instruct them in the orderly arrangement of knowledge, and to draw attention to the beauty of many of Nature's products. But there is more than that. Biology differs from physics and chemistry in dealing with that vast procession of living things which grow, reproduce and die, a process which never stands still, and of which the beginning is shrouded in mystery and the end impossible to foresee.

A cinema operator may stop a film to permit more careful examination of a scene, but the full meaning of the picture cannot be grasped unless it is regarded as one of a sequence, many others coming before and after. So the biologist may take his separate facts, e.g. the tests for starch, or the study of the composition of the blood, and give them prolonged attention. But the biological significance of starch cannot be realized apart from an understanding of its place in a continually repeated sequence of photosynthesis and oxidation —the 'carbon cycle'. Nor does the biologist study blood merely as a liquid with certain constituents: it is a fluid in continual motion, a veritable liquid highway, along which cells 'barter' and exchange their contents, where chemical reactions go forward or are reversed, where chemical messengers deliver their instructions, where materials are immediately available for the repair of wounds, where wandering 'police' cells deal with invading germs and a whole army of specifics is at hand to deal with their poisons.

It is the task of the teacher to make the pupil aware of the ever-changing condition of the biological material he examines. This should be so constantly emphasized that, in the end, the pupil no longer sees a flower, for example, just as it is for the moments when it is under observation. He should be conscious that some days ago it was a bud, its parts indistinguishable, protected in its calyx; that some living force lengthened its stalk, opened its calyx, developed its separate parts; that later the plant, through the flower, by itself, or aided by the presence of neighbours of its own sort, or helped by the wind, or insects, or water, or some other agency, will produce the means for the survival of its kind. In due course only the persistent seeds will remain, to begin a new life, repeating the old, while the rest of the flower, having served its turn, will perish and return to the earth which nourished it. When the pupil looks at the flower he should see it not only as a 'specimen' but as a living thing at a particular stage in a continual process of growth and change. Similarly, when he examines a lump of earth he must recognize it, not as something dead, but as a collection of materials undergoing physical changes and full of living organisms incessantly at work to bring about or accelerate chemical changes, the whole providing anchorage and nourishment for plants whose survival depends on the continuance of these invisible processes. Biology is a study of living organisms, not dead ones.

Other parts of the General Science syllabus have their own central ideas: for instance, mechanics is based upon the idea of 'work'; chemistry is the study of changes in the composition of molecules; physics is concerned with the measurement of certain units and energy relationships. These ideas permeate every aspect of the respective branches of science: the teacher of General Science has no small task to keep them clear in his own mind as he deals with his wide variety of subject matter. Yet, unless he does so, and brings them consciously to the attention of his pupils whenever possible, he fails in one of the finest aspects of his duty—to try to instil a genuine appreciation of science.

Growth of interest and stimulation of imagination

The teacher of science frequently emphasizes the smallness of the atoms, these 'bricks' of which the material world is made. He tells his class that no human eye can ever hope to see them, that no ordinary microscope is powerful enough to show them, that not even the latest electron-microscope will enable a scientist to see an atom. How, then, should a teacher reply when a pupil asks, 'If an atom is too small to see, how do you know there are such things?'

He should not answer 'You wouldn't understand', or 'There is no time to answer this question', or 'Perhaps in a year or two we will deal with the matter'. He should remember instead that:

(*a*) The motto 'Strike while the iron is hot' is always applicable in teaching.

(*b*) He must beware lest failure to provide some answer creates an impression that he does not know. Such a suspicion gains ground if pupils are frequently put off, and the class loses confidence in the teacher and in the science he professes to teach.

(*c*) Although the relevant calculations may be beyond the ability of the pupil to reproduce, or even to follow, yet most of the class are likely to have a little knowledge upon which an answer may be based. It is often possible to appreciate the 'argument' used by scientists, even when the facts upon which it is based are only faintly understood. The 'proofs' of many theories do not depend on direct demonstration. They are built on an accumulation of evidence all pointing in the same direction. For instance:—

(i) The acceptance of organic evolution is not based on any single argument. The distribution of animals and plants; classification of living things in orderly sequence, each class differing slightly from the next; the existence of fossils; the clues provided by vestigial remains; all these build up a confidence, if not a certainty, that the idea is correct.

(ii) The scientists' estimates of the age of the earth are based upon measurements of the thickness of layers of sedimentary rocks, on theories about the influence of tides, on the shape of the solar system, on the rate of cooling of the earth, on the percentage of lead in certain radio-active minerals, and so on.

(iii) The estimates of the height of the earth's atmosphere are based upon the variation of air pressure with altitude, on radio phenomena connected with the Heaviside and Appleton layers in the stratosphere, on the height at which meteors become visible, on data obtained from experiments with rockets, and so on.

The more nearly conclusions reached by different methods agree with one another, the more confident is the scientist in the accuracy of his final figures and the theories he advances.

Similarly the proof of the existence of atoms and molecules is based upon evidence drawn from many sources. Hence at least a partial answer to the pupil's question may be given by a brief outline such as the following:—

(1) Data supporting our belief in the existence of atoms and molecules—

(*a*) The most obvious evidence is the fact of 'the Brownian movement', easily seen under a microscope of moderate power.

(*b*) The facts of osmosis and diffusion are simply explained if particles of matter are small and in constant motion.

(*c*) The conduction of heat is easily 'explained' on the theory of molecules in motion.

(*d*) The ideas of molecular movement enable us to account for the fact of gas pressure, its variation with temperature, and the way in which gases do not invariably behave as Boyle's law would lead us to expect.

(*e*) The chemical laws of constant composition and of multiple and reciprocal proportions are neatly 'explained' if the existence of atoms is assumed.

(*f*) The properties of magnets, the mechanism of electrolysis, the emanation of charged particles of helium from radio-active bodies, add to the evidence for the existence of atoms and molecules.

(2) There are various methods of calculating the sizes of atoms and molecules—

(*a*) The size of the smallest particle that may be seen under a powerful microscope can be estimated. The atom must be smaller than this.

(*b*) A more direct measurement is that used in finding the mass and charge of the particles given off from radio-active bodies and in X-ray tubes. The calculations are based on the way in which the radiations are deflected from their paths by the influence of magnetic fields.

(*c*) A method has been worked out by which, from the rate of movement of electrically charged particles of fog (produced artificially in a small box), the size of both particle and charge can be obtained.

(*d*) It can be shown that particles in crystals are neatly arranged in rows. By using X-rays the spacing of the rows can be measured and hence the maximum size of the molecules determined.

(*e*) The blue colour of the sky has provided a method of estimating the size of particle which could cause the absorption of red light and the dispersal of the blue light.

Such lists and the 'explanations' involved may be expanded and adapted according to the age and ability of the class. The pupil may not be able to follow exactly how such methods are worked out in practice. The teacher himself may not know much more; but a complete grasp of the details is not necessary. That is for the technical expert or the research worker. It is sufficient if the pupil has some understanding of the methods, and can begin to appreciate the persistence and ingenuity of the scientists who devise and apply them.

Thus a simple, perhaps casual, question can give an alert teacher the opportunity to illustrate scientific methods and to fulfil one purpose of the teaching of General Science—the stimulation of the student's imagination.

Serving the community

The ideals of service should be encouraged throughout all phases of school life. Science classes often provide special opportunities, the following being one example.

Keeping weather records—If the economy of a country is to be wisely planned, various facts about the weather must be known. These include a knowledge of the average rainfall of an area, the distribution of rainfall throughout the year, the average temperatures at different seasons, and the humidity of the air. Agricultural departments need the information so that they may give advice about the most suitable crops to grow. Forestry departments can plan their programme of reafforestation only when the climatic conditions are known. Irrigation departments need the information so that an effective policy of water conservation and distribution may be adopted. Medical departments compare weather records with the times and frequency of outbreaks of such diseases as malaria, typhoid, and cholera: it may be possible to forecast the probability of epidemics and thus to be ready for any emergency.

Schools should be prepared to organize the keeping of meteorological records. The task gives pupils training in the reading of instruments, emphasizes the need for dependability in making measurements regularly and without fail, develops in them a sense of responsibility, and gives them the opportunity of doing useful service without expectation of reward.

The maximum, minimum, and the wet and dry bulb thermometers are kept outdoors in a ventilated box of standard size and pattern. It is called a Stevenson screen. The instruments are read at the same hour each day (usually 9 a.m.) and the maximum and minimum indices are then re-set for the next 24 hours.

The rain-gauge is placed so that its top is a foot above the ground on a level site well removed from trees or other obstructions. The rainfall is recorded daily, again usually at 9 a.m.

Similarly, the barometer, usually the Fortin standard mercury type kept in the laboratory, is read daily at the same time as the other instruments.

The readings made on a certain day, say the 17th of the month, are recorded thus: the maximum temperature is recorded against the 16th day, because the highest temperature was almost certainly the temperature of the previous afternoon. The rainfall is recorded against the 16th day, because most of the hours between 9 a.m. on the 16th and 9 a.m. on the 17th belong to the 16th day.

Relative humidity is obtained from the readings of the wet and dry bulb thermometers by means of a table such as 7 (*a*) in Appendix J, III, page 354.

The records provide data suitable for display in graphical form.

It is advisable for the teacher to get in touch with the nearest Meteorological department. Officers from the department will usually advise on the selection and placing of instruments, and on the keeping of records. It is not to be expected that the school should make corrections for altitude, temperature, etc., although this may be done by more advanced classes.

Monthly summaries of the readings should be prepared and exhibited on the notice board, and a copy sent to the local Meteorological office, which will usually supply forms for the purpose.

CHAPTER VI

The Teacher and his Methods

A teacher may appreciate the place of science in the modern world and in the school curriculum; he may have considered how best to select and arrange a syllabus; but this is all preliminary to his real task. The business of the teacher is to teach. This may sound like a platitude; it is none the less true for that. A man may know the necessary facts, he may be ingenious in the discovery of new ones, but his ability to teach a class is a skill of another order altogether. Some teachers, from the start, have a 'flair' for teaching, they possess some subtle ability to awaken the interest and gain the confidence of their pupils. Others have less initial advantages. None are so naturally gifted that they cannot benefit from a study of teaching methods; few are so naturally unsuited that they cannot improve their skill by thinking about how best to teach. It is the purpose of this chapter to discuss class-room techniques.

THE LECTURE METHOD

The lecture method enables the teacher:

(*a*) to cover the syllabus quickly;

(*b*) to collect and summarize the results of pupils' practical work;

(*c*) to open up a discussion as to where previous work may be leading, and to obtain suggestions for further inquiry;

(*d*) to introduce a new topic, collecting together what information the class already possesses, and outlining the sort of information that will be sought;

(*e*) to inform the class where relevant background material may be found; where certain objects may be seen, certain operations watched; in what periodicals appropriate articles or advertisements may be found or looked for; in what shops certain pieces of apparatus or advertisement displays may be seen; and so on.

The lecture method is most effectively used when as many members of the class as possible can be drawn into a discussion, when charts bought or prepared by the teacher are ready to hand, and when he has suitable summaries in his teaching notes ready to be written on the blackboard. Although the matter for summaries should, as far as possible, be obtained from the class by question and answer, the teacher must not rely on getting a complete summary in this way. Points are apt to be overlooked.

Limitations of the lecture method—Experimental facts are the basis of scientific knowledge. In the lecture method this is apt to be overlooked. When a teacher lectures he is playing a larger part in the lesson than he should, and the class is apt to be doing far too little. In general the less a teacher needs to lecture the better.

Examples of the lecture method

(A) *A lesson on 'Human blood'*

Revision of earlier work—(*a*) The part played by the red colouring matter of the blood; the way in which oxygen is transported all over the body and carbon dioxide is removed.

(*b*) Digestion. The blood travels either to the kidneys, the lining of the intestines, or to the muscles; or it travels through the lungs. Blood carries soluble food from the intestines, first through the liver, then to the heart, and finally all round the body, so that cells everywhere can be nourished and waste products washed away.

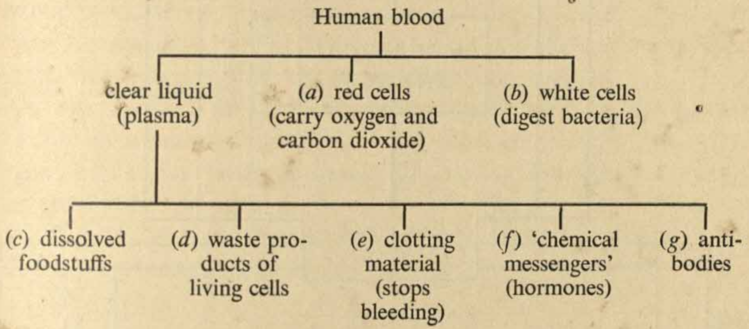
(*c*) Excretion. The blood constantly circulates, and in the course of a few minutes practically every drop of blood will have passed through the kidneys, liver and lungs. The kidneys extract salts, phosphates and nitrates, the liver makes dangerous nitrogen compounds harmless and stores excess of sugar. The lungs provide the escape route for carbon dioxide.

New matter—(*d*) What happens when we cut ourselves? We bleed. At last a clot forms to close the cut. The function of fibrin.

(*e*) Why do we grow, or stop growing? Glands produce chemicals (hormones) that control the body's growth. How we react to an emergency. The part played by adrenalin.

(*f*) Why do we recover from some illnesses, and how do we avoid others? Some diseases are caused by microbes which get into the blood and discharge poisons. The body combats this in two ways: the white cells (like amoeba) in the blood wrap themselves around microbes and digest them; and certain chemicals, called 'anti-bodies' are prepared in the blood to counter the poisons discharged by the microbes. The white cells die in places where there is much infection and are discharged as 'pus' from suppurating wounds.

Summary—Collecting all this together a summary of the main constituents of the blood can now be drawn up:—


Human blood
clear liquid (plasma)
(*a*) red cells (carry oxygen and carbon dioxide)
(*b*) white cells (digest bacteria)
(*c*) dissolved foodstuffs
(*d*) waste products of living cells
(*e*) clotting material (stops bleeding)
(*f*) 'chemical messengers' (hormones)
(*g*) anti-bodies

This lesson can be used to lead on to:—(i) A study of simple forms of life: amoeba, obelia, hydra, or whatever are the most easily available specimens of protozoa, etc., in the neighbourhood of the school. (ii) Inoculation against disease and the nature of the injected fluid. There are two sorts of fluids. One sort contains 'anti-bodies' which have been prepared in the blood of some other creature and are immediately available to counteract the poisons in the patient's blood. The other sort, injected into a person when in normal health, contains microbes which have been made weak and harmless. The body reacts to these as it does to the normal active microbes of the same kind, and produces the appropriate anti-bodies. These remain in the blood ready to counteract the poisons which would be produced were the person exposed to serious infection by active microbes of that kind. (iii) Instruction in first-aid.

(B) *Summary of a series of lessons on the conservation and transformation of energy*—Any one form of energy can be transformed directly into any other form of energy. Moreover, a certain definite amount of one kind of energy is exactly equal to a certain definite amount of each of the other kinds.

Examples of how one form of energy may be converted into another are shown in the chart (Figure 7).

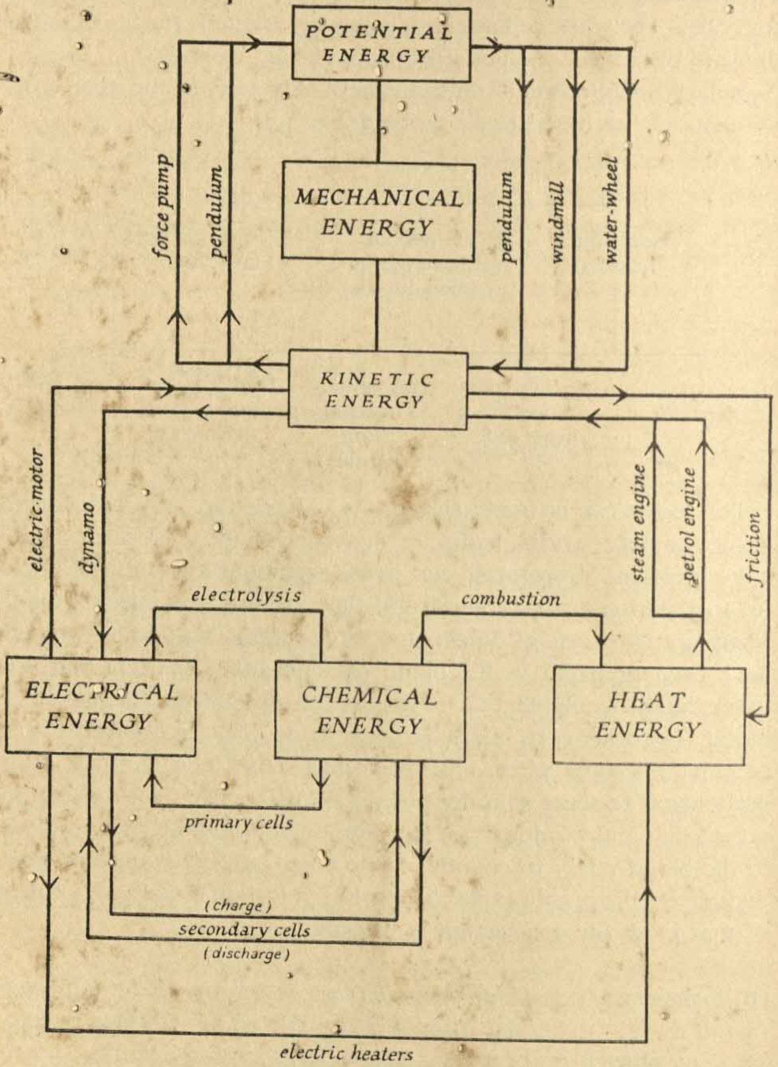


FIGURE 7.—A chart: the transformation of energy

Note—Charts of this kind are excellent for providing summaries and as a method of revision. They can be expanded and improved as the pupils' experience and knowledge increases.

(C) *Summary of a lesson on jets and sprays*—A jet is a stream, usually of gas or liquid, forced through a small opening.

[*Note*—The teacher should have described briefly, with simple diagrams, his selected examples. These should consist, as far as possible, of practical illustrations of the use of jets to be seen or examined locally: for instance, a garden hose; a fire-engine hose; hoses for washing out ore in a mine; a laboratory wash-bottle; water, steam or gas turbines; turbo-jet aero engines.]

A region of low pressure is formed around a fast-moving jet, so that the surrounding fluid (e.g. air or water) tends to flow into this region, and to mix with the stream. Thus a liquid can be drawn out of a small tube by a jet of air near by, and in the process is broken up into droplets. A spray consists of such tiny drops dispersed in a jet of gas. Further examples of this principle are given below:

Device or Process	*Jet of:*	*Substance drawn in:*
Bunsen burner, Blow-lamp; etc.	Coal-gas, Paraffin vapour; etc.	Air
Scent spray, Insecticide 'gun'; etc.	Air	Scent solution, Liquid insecticide; etc.
Spray 'gun' (for painting motor-cars; etc.)	Air	Cellulose paint
Carburettor (e.g. of an automobile engine)	Air	Petrol
Powder spray	Air	Pyrethrum powder, 'D.D.T.' powder, etc.
Vacuum brakes (of steam trains)	Steam	Air
Filter pump	Water	Air or other gas to be passed through, or removed from, an apparatus

This list is merely a typical sample. A teacher should base his own list on things familiar to his pupils, extending it whenever the opportunity occurs.

(D) *The pupil's note-book record of a lesson on the structural importance of triangles*—If four rulers are joined by four nails to form a quadrilateral (Figure 8 (*a*) and (*b*)), the structure can be pushed into various shapes. It is not rigid.

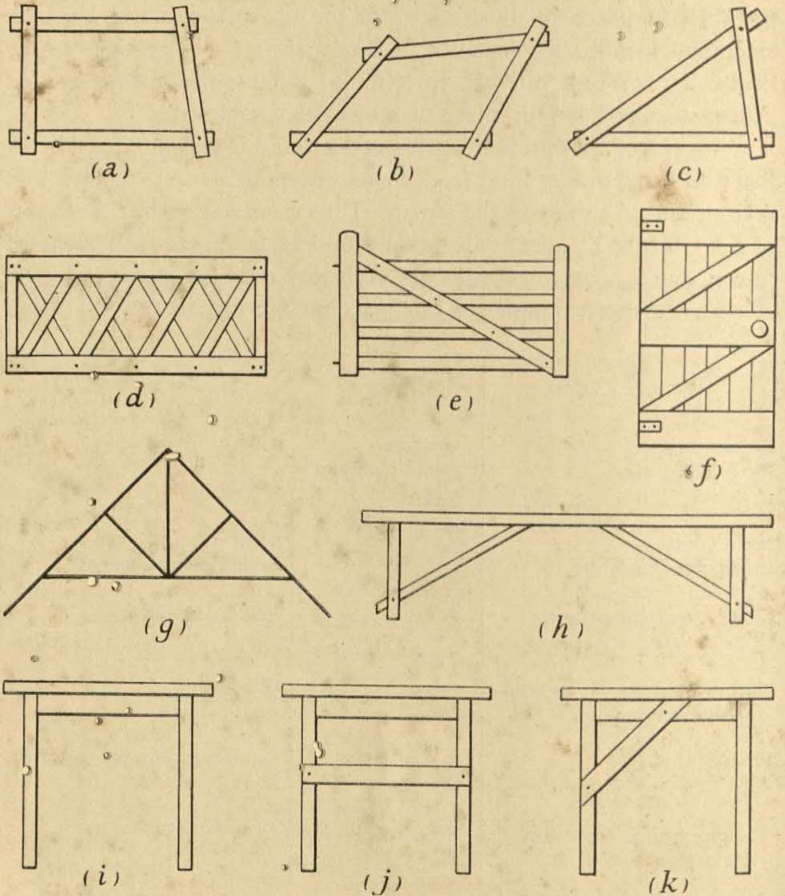


FIGURE 8.—The structural importance of triangles

(*a*) and (*b*)—Four rods form a quadrilateral which may be pushed into various shapes

(*c*)—Three rods form a triangle, which is rigid

(*d*) to (*h*)—The girders of a bridge, a gate, a door, a roof truss and a bench are all made rigid by the triangular construction

(*i*) and (*j*)—The table is not firm (compare the quadrilateral)

(*k*)—The table becomes rigid (note the triangle)

But if three rulers are joined at the ends by three nails to form a triangle, the structure can have only one shape. It is rigid (Figure 8 (*c*)).

Examples of rigid frameworks built up of triangles are shown in Figure 8 (*d*) to (*h*).

When a table becomes shaky and must be made rigid, a piece of wood is nailed on in such a way that a triangle is constructed, as shown in Figure 8 (*k*).

[When other examples are seen, they should be added to the list, with simple diagrams.]

THE DEMONSTRATION METHOD

This method is desirable:

(*a*) When the apparatus to be used is costly and unsuitable for juniors to handle.

(*b*) When the apparatus is very sensitive and may be damaged by clumsy handling.

(*c*) When several experiments must be done during one lesson, so that they may be seen together and the connexion between them established. (This connexion might not be seen if the experiments were spread over several long-separated lessons, or were distributed among various groups of pupils.)

(*d*) When a quick revision of some project or principle is desirable.

(*e*) When the experiment involves slight danger: for example, in the burning of hydrogen to form water, or in the demonstration of what happens when an electric fuse is blown by an ordinary domestic current.

The following are some of the points to be remembered if the demonstration method is to prove effective:

(*a*) When a teacher is carrying out an experiment, it is absolutely essential that every member of the class is able to see what is happening. This is frequently impossible when the teacher's bench is level with, or higher than, the students' benches. For this reason it is an advantage to have a lecture room in which the pupils sit at benches arranged in tiers. Everyone then has a good view of what is going on. If no lecture room is available, there are several ways of enabling pupils to get a better view.

(i) The students may be permitted to sit on laboratory stools placed on top of their benches. From this height they can more easily see the experiments that are being carried out. Window-sill seats may also be used. Such arrangements, however, are only possible where the discipline is good.

(ii) The teacher can carry out the experiment on one of the front students' benches. He can then instruct the class to stand around the bench, none to approach nearer than, say, 10 feet, so that all may have a clear view. The difficulty about this method is that the teacher may be some distance away from the blackboard.

(iii) A large mirror can be erected at an angle above the teacher's bench. The class may see what is going on by looking at the reflection in the mirror. This is a very useful method for enabling pupils to do what should otherwise never be permitted—to look *into* test tubes while the contents are being heated. It also enables them to get a good view of instruments which are laid flat on the bench, or which have horizontal scales, such as magnetometers, ammeters, etc. The difficulties of the method are that if the mirror is small it must be placed fairly closely over the apparatus, sometimes making it awkward for the teacher to manipulate the apparatus. If the mirror is suspended rather higher, it has to be much larger, say 3 feet × 2 feet as a minimum. To suspend it conveniently is not always easy, though a practical teacher should be able to manage it with the aid of strings and four pulleys fixed in the ceiling or in the ceiling joists.

(*b*) Apparatus used in a demonstration should be as large as possible, and graduations on any instruments should be prominent. (It should be possible for *all* pupils to see the details of the experiment clearly.) For example, in finding the density of iron, the teacher can hang a 5 Kg. iron weight on a 5 Kg. spring balance and then immerse it in a bucket of water.

(*c*) Attention must be given to the adequate lighting of the bench; and, where possible, there should be additional illumination for specific experiments. For instance, an experiment illustrating convection in liquids can be made more impressive by the placing of a lamp behind the tubes.

(*d*) A blackboard extending across almost the whole length of the wall, behind the teacher's demonstration bench, is desirable. During the lesson the teacher will probably find it convenient to summarize the principles and other matters the demonstration is designed to show. This summary can be written on the extreme left of the board, being added to as the lesson advances. On the centre of the board can be put the more detailed descriptions of the experiment. On the right there should still be room for writing the measurements recorded: weights, temperatures, etc. Notice-board or blackboard space on the same wall is desirable for charts, pictures and other illustrative material.

(*e*) The teacher must have the attention of the class. To that end he may, with advantage, be a bit of a 'showman'. To time a phrase rightly, to inspire a class with a sense of the dramatic, to arouse an atmosphere of suspense just before the crucial point of an experiment, is an art as useful to a teacher of science as it is essential to an actor.

(*f*) The experiments demonstrated must be consciously connected with things seen and handled by the pupils.

(*g*) The demonstrations must fit into the sequence of experiments which the pupils carry out themselves.

(*h*) A teacher should obtain the assistance, in turn, of individual members of the class. Such pupils may read scales, describe reactions to the rest of the class, at suitable moments help the teacher to manipulate the apparatus, besides making themselves useful in more general ways.

(*j*) When several things are to be used during the lesson, they should not be displayed all at once. A wealth of apparatus may impress the student, but it can also confuse him. Apparatus, as required, should be put and used in a prominent position. Before and after use it should be placed well to one side, though not necessarily out of sight.

(*k*) Probably the teacher has his greatest chance of showing his skill when compelled to use inadequate, or even faulty, apparatus. (It is the incompetents, lacking resource, who make most complaints about the available tools.) Of course skill is employed to the greatest advantage in the use of first-class apparatus, but even the best apparatus does not ensure that experiments will always go through as planned. Failure is inexcusable if it means that the teacher has not tried the experiment out himself before demonstrating it to a class. But, sometimes, for one reason or another, things happen which are beyond the control of the teacher. To be able to deal with experiments which have 'gone wrong', to be able to draw useful conclusions from experiments which have failed in their original purpose, is the mark of a good teacher.

(*l*) As in the case of other teaching methods, time and seasons for practical work should be considered. The time to study locusts—whether or not the word 'locust' occurs in the syllabus—is when a swarm appears, for the life history, movements and control of these insects are of immense importance. In places where there are distinct seasonal changes it is particularly desirable to keep the biological sections of the syllabus flexible, so that plants and animals may be studied at the most appropriate times. Climatic conditions affect other kinds of experiment. For example, static electricity is not a suitable topic for the rainy season; it is inadvisable to choose the hottest season for the use of ice in the laboratory; deliquescence is best shown in wet weather and efflorescence in dry; and it is easier to use yellow phosphorus on a cool day. Teachers are recommended to keep a calendar to remind them of these and similar cases.

Examples of the demonstration method

(A) *A lesson on 'Electro-magnetism'*—The purpose of the lesson is to give a brief survey of the various ways in which electromagnetism manifests itself. The facts to be demonstrated may be summarized as follows:—

(1) Using coil and magnet:

(i) With the coil fixed, a current is passed through the coil.—The magnet (e.g. a magnetic compass), suspended freely inside the coil, moves.

(ii) With the coil fixed, the magnet is moved.—A current is produced in the coil.

(iii) With the magnet fixed, a current is passed through the coil, which is freely suspended.—The coil moves.

(iv) With the magnet fixed, the coil is moved.—A current is produced in the coil.

(2) Using two coils close together:

(v) When a current is suddenly passed through one coil, without an iron core, a current flows in the other coil.

(vi) With an iron core common to both coils, a current suddenly passed through one coil produces in the other coil a larger current than was produced in experiment (v). (The coils should each have about 500 turns of wire, and the galvanometer used for detecting the current should preferably have a centre zero.)

The six experiments are carried out, one by one, and a diagram, with a brief reminder of what happens, is written on the centre of the blackboard for the class to copy. There is rarely need to write much on the blackboard because the experiments are described in most General Science text-books.

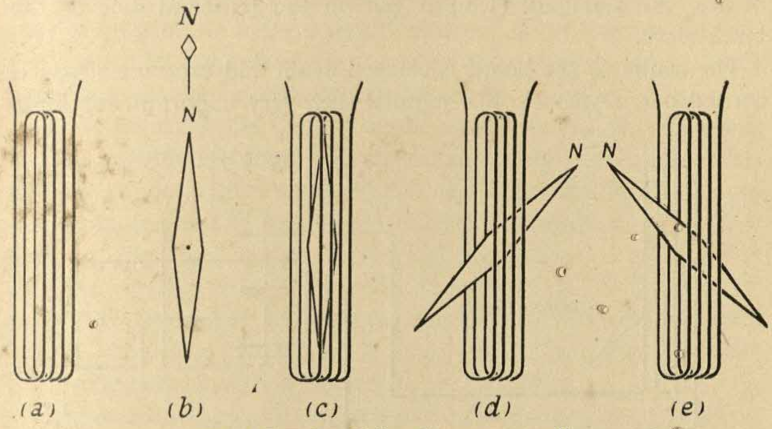


FIGURE 9.—Coil and compass needle

(*a*) Coil (*b*) Compass needle
(*c*) The compass needle is suspended inside the coil
(*d*) A current is passed through the coil
(*e*) The direction of the current is reversed

The diagram (Figure 9) illustrates the first experiment, and may be put on the blackboard for the class to copy. After the experiment, the first part of the summary, (1.i) above, is written on the left side of the blackboard. The centre of the blackboard is then cleaned, and experiment (ii) is carried out. Again diagrams and brief account are put in the centre of the blackboard, while on the left-hand side is added the summary, as in (1.ii) above.

The centre of the blackboard is cleaned once more and experiment (iii) is performed. The experiment is very important because it illustrates the working of all electric motors. This point should be mentioned, and a diagram of a motor drawn on the right-hand side of the board, but the sequence of experiments should not be delayed, at this stage, by a detailed discussion. (The experiments (i) to (vi) should be dealt with as quickly as is reasonably possible, and details about electric motors saved for a separate lesson. It may be noted, however, that the maximum twist that can be given to a coil is 180°. To twist it still more the current must be reversed.) Proceeding as before, the summary (1.iii) is put on the left-hand side of the blackboard.

The centre of the board is cleaned again and experiment (iv) is carried out. Dynamos, like motors, such very important machines in this present age, may be mentioned, details being left for a subsequent lesson. The summary (1.iv) is added to the left side of the blackboard.

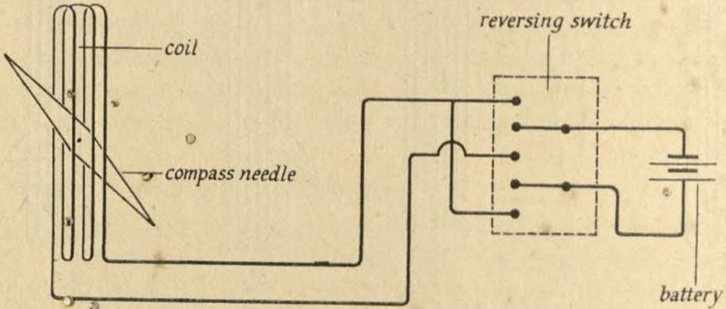


FIGURE 10.—A model electric 'telegraph' (and see Figure 9)

The procedure for experiments (v) and (vi) is similar, transformers being mentioned, but the detailed discussion of them and their uses being left for a subsequent lesson. Once the six experiments have been done, and the diagrams and short notes entered in the students' note-books, the whole series may be repeated when there is enough time to deal with the practical applications of the phenomena.

Experiment (i) leads on to a discussion of the electric telegraph, and apparatus can be adapted to provide a model (see Figures 9 and 10). The magnetic compass may be placed flat on the bench, with a mirror at an angle of 45° over it, or a compass needle may be suspended vertically to swing in an east-west plane. The two ends of the coil may be attached by long wires to a battery and reversing key at the back of the room, where the key may be operated by one of the pupils. If its movement is not easily visible from a distance, the magnetic needle may be attached to the centre of a clearly marked circle of paper. Experiment (iii) leads to an account of the construction of galvanometers, ammeters, voltmeters, and D.C. (direct current) and A.C. (alternating current) motors, including 'self-starter' motors of cars. A discarded electric motor from an old car may be brought to the class and taken to pieces to show its construction. It may be possible to make a model motor. A keen teacher will take the opportunity of helping his pupils to make many models of such machines and instruments during out-of-school hours.

A model electric D.C. motor can be made by using a steel knitting needle, an ordinary cork, two small solid rubber corks, some fine D.C.C.[1] copper wire of about 36 S.W.G.,[2] some bare copper wire of thicker gauge, and a wide-ended horseshoe magnet. If this last is not available, four magnets can be tied together to a wooden block as shown in Figure 11. Support for the apparatus can be given by using four three-inch pins, or needles, stuck into the wooden baseboard. About 6 to 8 volts are required to drive the motor. (To start it the axle may have to be spun with the fingers.)

Experiment (iv) leads to an account of electric dynamos, including the dynamos of a car and a bicycle lighting set. More important still, it is a suitable occasion for considering the way in which the natural power resources of a country—e.g. coal, oil, rivers and mountain streams, tides and wind—can be utilized. During these lessons there should be plenty of opportunity for displaying pictures, charts, diagrams, and for examining discarded dynamos from old cars. It may be possible, as described later in this chapter, to organize a project round a power development scheme, or to arrange a visit to a local electric generating station.

Experiments (v) and (vi) can lead to a discussion on transformers, their use in permitting electricity to be conducted economically over long distances, and the reason why electric generating stations usually provide alternating rather than direct current. Discarded transformers, once used in reducing the voltage of the current supplied to electric refrigerators, can perhaps be found and examined. A manufacturer's large-scale chart of a car, with pinned-on paper arrows, can be used to indicate the positions usually occupied by the starter motor (experiment iii), dynamo (iv) and coil (vi).

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[1] Double cotton covered.

[2] Standard wire gauge.

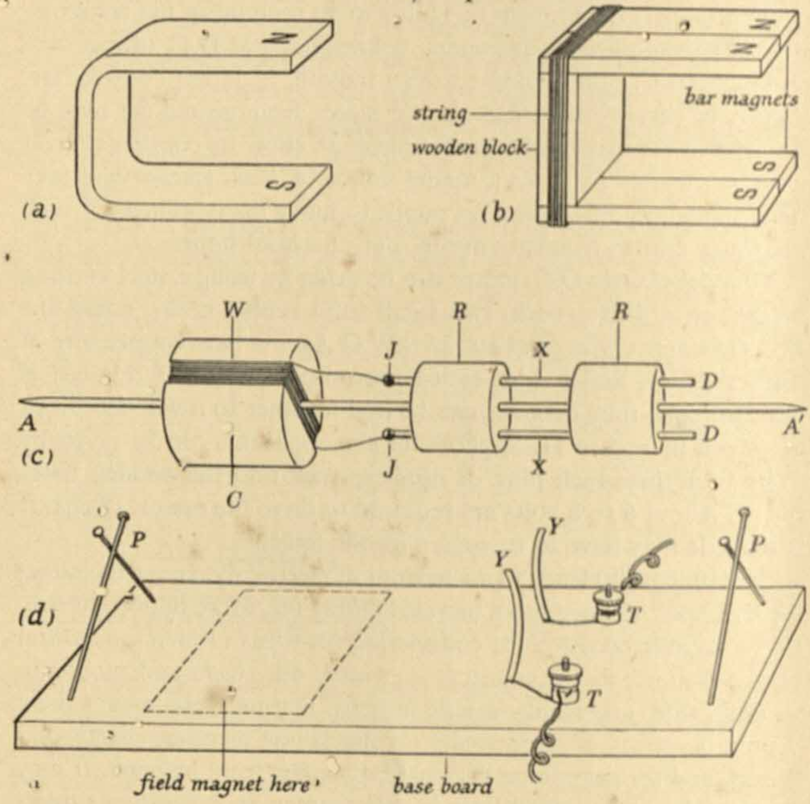


FIGURE 11.—A simple model of an electric motor

Note—Pupils should draw a diagram, not a perspective sketch. They should also use 'labels' for the parts, instead of a key.

(*a*) Field magnet—'horseshoe'
(*b*) Field magnet built up from four bar magnets
(*c*) Armature, etc.

AA'—Steel knitting needle. C—Cork. D—Bare copper wire, S.W.G. 18. J—Soldered joints of wire. R—Rubber corks. W—300 turns of double-cotton-covered copper wire, S.W.G. 36, wound in slot in cork. X—Contacts for 'brushes'.

(*d*) Base

P—Crossed pins to act as bearings. T—Terminals. Y—'Brushes' (bare copper wire, S.W.G. 26).

(B) *Pupil's notes of a lesson on colour*

White light analysed:

(*a*) Newton's expt. (See text-book)
(*b*) Rainbow (Colours V.I.B.G.Y.O.R.) (See text-book)

White light synthesized:

(*a*) Newton's expt. with 2 prisms (See text-book)
(*b*) Newton's disc (See text-book)
(*c*) Combined light of 3 primaries

Experiments with coloured gelatine transparencies[1] :

The primary colours:—*red*, *green*, *blue*.
The complementary colours:—*yellow* (= red + green)
magenta (= red + blue)
peacock (= green + blue)

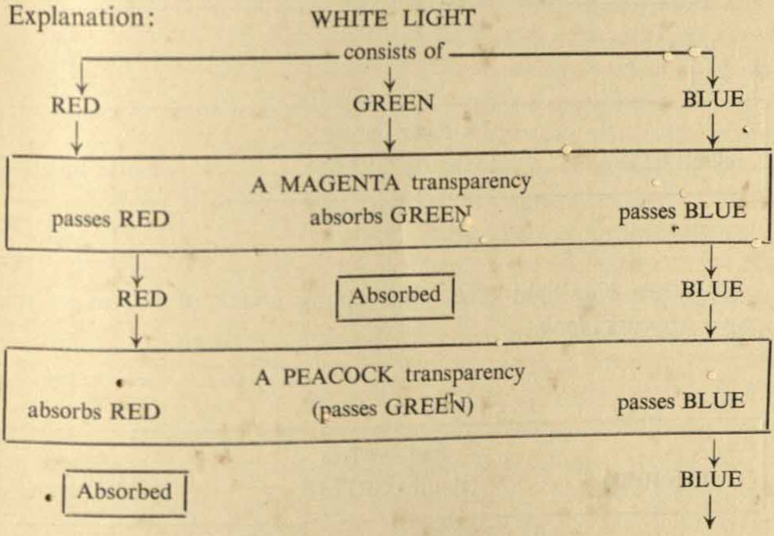
(*Note: magenta* is also called *purple*
peacock is also called *blue-green*)

Adding colours in various proportions. (See text-book)

Subtracting colours:—

(*a*) Place a *magenta* and a *peacock* transparency one upon the other and look through them both at white light. The colour seen is *blue*.

Explanation:



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[1] Or coloured electric lamps.

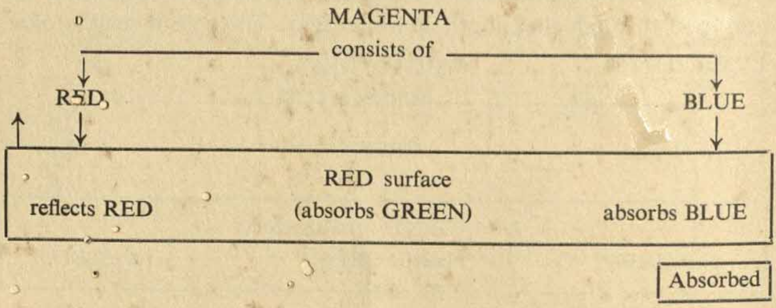
[Each pupil now produces charts similar to the above showing how to use *yellow* and *magenta* transparencies to allow only *red* to pass through, and how to use *yellow* and *peacock* transparencies to allow only *green* to pass through.]

Colour photography (Films and transparencies only) — The film contains many minute grains of material, some sensitive to red light, some to green, and others to blue. The film is exposed, and then developed in a chemical which colours the red-sensitive particles a mixture of yellow and magenta, colours the green-sensitive particles a mixture of yellow and peacock, and colours the blue-sensitive particles a mixture of magenta and peacock. When the negative is held up to a white light, the parts of the film that were exposed to blue light appear blue, and so on.

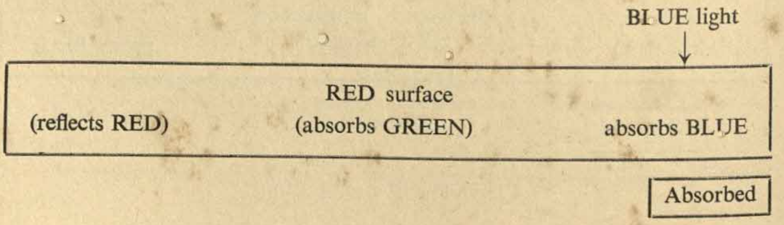
(*b*) Coloured crayons and paints absorb all colours except those which are seen.

(i) When *magenta* light alone falls upon a piece of *red* paper, the paper continues to appear *red.*

Explanation:



(ii) When *blue* light alone falls upon a piece of *red* paper the paper appears *black.*



[The notes can be made more vivid if each pupil colours the diagrams lightly with crayons. The transparencies and the coloured lights, up to the places where they are absorbed, can be shown in appropriate colours.]

(iii) Why mixing *blue* and *yellow paint* makes *green.*

Pigments and dyes are not pure spectral colours. *Blue paint* reflects *blue* and some *green*, but absorbs all the rest. The eye only notices the prominent *blue*. *Yellow paint* reflects *yellow* and some *green*, but absorbs all the rest. The eye only notices the *yellow.*

The *mixture:*

BLUE paint	absorbs YELLOW	reflects GREEN	reflects BLUE
YELLOW paint	reflects YELLOW	reflects GREEN	absorbs BLUE

The *blue* pigment cuts out the *yellow*. The *yellow* pigment cuts out the *blue*. Only the *green* remains and is seen.

THE LABORATORY METHOD

Quite apart from the logical necessity of experimental work in a science course, it is a fact that an object handled impresses itself more firmly on the mind than an object merely seen at a distance or in an illustration. Most children like doing things with their hands. Practical work provides an activity which can be profitable and emotionally satisfying. Organized practical work takes this aspect of the child's needs into account. But some observations about practical work in science classes must be emphasized here.

(i) The work needs to be *worth doing.* The mechanical repetition of some experiment described in a book may be hardly worth the time involved. It can be made of more value, perhaps, by some modifications. If the text-book describes the germination of a bean, then a student may do the experiment using a bean of another species, or a pea, a nasturtium, a sweetcorn or maize, or a seed of a member of the widely distributed cucumber family. If various groups of pupils set up similar apparatus and use a different seed, then, at the end of the lesson, the experiments may be brought together, in a convenient place, for continued observation. Thus every pupil has an opportunity of seeing several seeds instead of one. If the families represented include, as in the examples given, both mono-cotyledons and di-cotyledons, an opportunity is given to a class to 'have another look', to make a last critical examination before the experiment is abandoned. This 'last look' is a valuable habit to encourage. In the instance here given a class may find out, for itself, that fundamental differences between plants may be revealed by an examination of the seed-leaves.

(ii) The experiment must be such that what is to be demonstrated, or proved, is quite clear from the beginning. Further, the difficulty of performing the experiment must not be so great as to distract attention from its purpose.

(iii) The object of the experiment must be exactly described. Some of the results of experiments conducted in a school laboratory may be already known to the pupils. Accounts of them are probably given in the text-books which they use. Experiments to be done with hydrogen, or on plant respiration, for example, should not necessarily be described: 'To discover that water is formed when hydrogen burns', and 'To find out if plants breathe'. Better descriptions are: 'To show that water is formed when hydrogen burns', and 'To demonstrate that plants "breathe",' or 'To confirm that plants absorb oxygen in sunlight'. Use of the word 'discover', when the results are already known, makes practical work appear unreal, an effect which must be avoided at all costs.

(iv) The opportunity should be taken of making detailed and critical examination of the accounts written by pupils, and of the methods used to set out the results obtained.

(v) When any form of measuring instrument is required for the first time in an experiment, the teacher should give careful and detailed instructions for its use. Reasons for the necessary care and accuracy should always be given, and the class reminded of them from time to time. The pupils' manipulation and reading of instruments should be checked whenever possible.

(vi) The opportunity should also be taken of discussing the degree of accuracy to be expected. If, for instance, the density of a solid object is to be found, two measurements are required, the volume and the weight. Supposing the volume is measured and found to be 25 c.c., but might possibly be 24·5 or 25·5 c.c., there is a possible error of up to 1 c.c. in the volume noted, that is an error of 1 in 25, or 4 per cent. If the weight is found to be 50·05 grams, and the weighing is so accurate that an error of no more than 0·05 grams is likely, the weighing error is 0·05 in 50, that is one-tenth of one per cent. Errors due to measuring the volume are far greater than those due to weighing. In fact, it is a waste of time to carry out the weighing process to such a degree of accuracy when the volume measurement involves an error which may be so much larger. The final value for the density can never be stated to have an error of less than 4 per cent., no matter how accurately the weight of the object may be determined. This indicates why, in elementary experiments in physics, the use of an accurate chemical balance is usually out of place. Spring balances give a result which is sufficiently accurate and more quickly obtained. In experiments on the determination of specific heat, the limiting factor is usually the accuracy of the thermometers used. In experiments on sound, a string, which, when plucked, gives a note in unison, or in harmony with another note, can rarely be measured with great accuracy. Calculations based on pupils' experimental results often imply, quite falsely, an accuracy which can only be obtained, in fact, by the use of far more sensitive apparatus than that likely to be used during a General Science course.

The laboratory method has its own particular uses. They are:

(*a*) To confirm something stated and described in a text-book.

(*b*) To examine various examples, especially local ones, in addition to those described in the text-book.

(*c*) To provide exercise in reading scales and making diagrams (including drawings of living material), and to make students acquainted with the various skills they need to master.

(*d*) To accustom the pupils to using the various simple hand tools of the scientist: seekers (blunt probes), scalpels, spatulas, pestles and mortars, blowpipes, tongs, tweezers and forceps, cork borers, glass-cutting instruments, etc.

(*e*) To provide opportunities for the exercise of ingenuity.

(*f*) To accustom the pupil to the scientific tradition of working in co-operation with others.

(*g*) To arouse a sense of curiosity and a desire to take active steps to satisfy it.

(*h*) To encourage a reliance on facts as distinct from opinions, and to develop a willingness to allow theories to be tested by experience.

The exercise of ingenuity—Primitive man would not have survived had he not possessed more ingenuity and powers of improvisation than the wild life around him. This power of improvisation is among man's most precious gifts. It can be improved by exercise. In many countries the leaders are anxious to develop minor industries in order to establish a more balanced economy, and thus render them less dependent on imports from overseas. Success will depend upon ability to improvise many of the essentials for these industries, if the products are to be adapted to local conditions, and not merely blind copies of what was previously imported. Yet craftsmen cannot be expected *suddenly* to develop the necessary ingenuity. These abilities, for the exercise and development of which laboratory experiments provide an opportunity, are usually gained only by long experience and the use of imagination.

This being the case it is sometimes good NOT to hand out to a pupil all the materials he may subsequently need for an experiment. A scientist first considers what has to be done, then he considers what apparatus will enable him to carry it out, and, if the equipment at his disposal seems unsuited or inadequate, he must try to improvise what he wants from the materials at hand.

Supposing, for example, that a student has to suspend a pendulum bob with a piece of string. The point from which the pendulum swings must be definite and rigid, and there are bad, good and better methods of suspension. If a pupil ties up a pendulum according to his own ideas, it is unlikely that he will choose the best way. The teacher can then profitably discuss the method adopted, and lead the student to see how, with a little ingenuity, an improved method of suspension can be arranged (see Figure 12).

The organization of pupils' experiments—Several methods are possible.

(1) Each pupil in the class may perform, at the same time, an identical experiment. He will gain practical skill, confirm facts, stimulate powers of observation, and refresh memory. Or, the class may be set a simple problem and, to solve it, may be told to work individually or in small groups (of not more than four pupils).

This method of class organization is suitable when the experiments require only simple apparatus of which there is a good supply. It is also appropriate when there is some slight risk of an accident, as a teacher can more easily supervise the activities of a class when all pupils are doing the same thing.

(2) Another method is to arrange a number of different experiments, all having some common purpose. The pupil, by himself, or working with not more than one or two others, does each experiment in turn. Having completed one experiment, he goes on to the next, which has just been carried out by some other pupil or group. This arrangement of work is economical of apparatus. Moreover, pupils are less likely to spend too much time comparing results with each other, and should develop more reliance on individual skill.

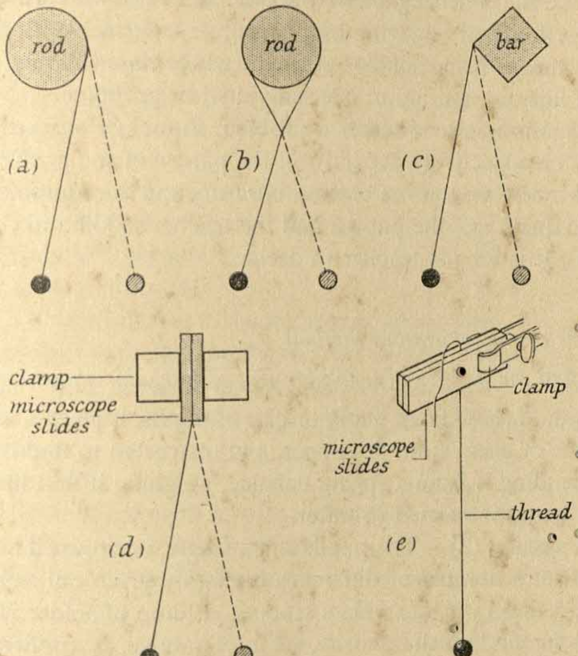


FIGURE 12.—The suspension of a simple pendulum

(*a*) BAD. The effective length of the thread alters during the swing
(*b*) BETTER. But the loop tends to move
(*c*) STILL BETTER. But the point of suspension is not yet stable
(*d*) and (*e*) BEST. The thread is firmly held between two microscope slides in a clamp

(3) A third arrangement may be adopted when a considerable amount of practical work, more than any one student has time for, must be done in order to obtain the required information. Not every member of the class will do all the experiments. The work is split up, and each part is done by a different student or group. To the increase of skill and the benefits gained from practical work will now be added the opportunity of engaging in a corporate exercise. With it should come a sense of responsibility, since the whole class will rely, for each piece of information, upon one individual or group.

The decision as to whether a problem should be worked at individually or collectively depends on the nature of the problem itself, the time available, the size of the laboratory and the equipment available, the quality of the pupils, and the teacher's skill and control of the class. It is for the teacher to decide.

Examples of the laboratory method

(A) *To find the density of a solid object of irregular shape*

First method (1) — Each pupil, or pair of pupils, is given a solid such as a piece of glass, iron, or copper, and instructed to find its density by suspending it from a spring balance, weighing it first in air, then while it hangs immersed in water.

Second method (2) — The pupils work singly, or grouped in pairs, as before. But a number of different objects are given out, e.g. a piece of iron, a brass weight, a glass stopper, a lump of solder. The same method for finding the density, as in (1) above, is applied to each object in turn, so that, simultaneously, the densities of different objects are being found by members of the class. Once the method of carrying out the experiment is understood, the determination of the density of the second, third, fourth, etc., object is carried out with increasing rapidity. (As the method does not vary, pupils need write out a full description of only one experiment.) The values found are collected by the teacher at the end of the lesson, and recorded on the blackboard. Against each value the name or initials of the person or group responsible should be added. Should any results be far different from the average, the inaccuracies stand out at once, Those responsible may be directed to examine their calculations again. If necessary they may be required to repeat the experiment. This also provides the teacher with an opportunity to point out to his class that the values for density given in a table such as that in Appendix J.I (1), page 351, are average values obtained from average samples. Every sample may not give the same value. Wide variations from average values also give the teacher an opportunity to discuss the possibility of experimental errors and the need to reduce these to a minimum. (It is a matter of surprise to most pupils that years may elapse between the discovery of a substance and the extraction of a sample sufficiently pure for its density to be determined.)

Both methods (1) and (2) assume that the school laboratory is equipped with many spring balances of a suitable range, and are concerned with only one method of finding density. A much more comprehensive series of experiments, more economical of apparatus, may be organized as follows:—

To find the density of:

(1) An object of regular shape, heavier than water.

(2) An object of irregular shape, heavier than water.

(3) An object of regular shape, lighter than water.

(4) An object of irregular shape, lighter than water.

(5) A liquid.

Methods to be used:

(*a*) Measurement with a ruler, calculation of volume, weighing.

(*b*) Weighing in air and in water.

(*c*) Measurement of displacement when floating on, and when fully immersed in, water.

(*d*) Weighing a solid in air, in water, and then in the liquid.

(*e*) Using a density bottle.

The objects and methods listed may be combined in various experiments:

1(*a*); 1(*b*); 2(*b*); 3(*a*); 3(*c*); 4(*c*); 5(*d*); 5(*e*). By repeating the different types two or more times, sufficient experiments can be provided for any number of pupils, whether working singly or in pairs.

Assuming the provision of an experiment at each of ten working places, and numbering the experiments in sequence from ONE to TEN, the experiments could be selected in this order:

Experiment ONE—(1.*a*)—Find the density of a small rectangular bar magnet

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Experiment TWO—(2.*b*)—Find the density of a glass stopper
,, THREE—(3.*c*)—Find the density of a wooden cube
,, FOUR—(5.*d*)—Find the density of kerosene
,, FIVE—(5.*e*)—Find the density of methylated spirits [1]
,, SIX—(3.*a*)—Find the density of a rectangular piece of cork
,, SEVEN—(1.*b*)—Find the density of a metal sphere (lead pendulum bob)
,, EIGHT—(4.*c*)—Find the density of an ordinary bottle cork
,, NINE—(5.*d*)—Find the density of turpentine
,, TEN—(5.*e*)—Find the density of glycerine [1]

The materials required for the experiments are placed in the appropriate working places. The pupils are sent to their allotted places and start their experiments. When all have finished each moves on to the experiment next higher in number. Those who were doing experiment TEN proceed to the working place where experiment ONE is provided. If each pupil does five experiments in sequence, he will have carried out the five methods of finding density, and the class as a whole will have found the density of ten different objects.

It may be noted here, before outlining the arrangement of such a series of experiments, that there are other series which can be treated similarly. Examples are:—experiments on methods of finding boiling point or melting point; simple titrations, including estimation of the hardness of water; neutralizing an alkali by an acid; examining and drawing the flowers belonging to several different species of plants, or the feet, or beaks, of birds of different families; comparing the bones of the feet of some common animals; and so on.

When members of a class are doing different experiments, or looking for different features in biological specimens, some sort of guidance must be provided with the apparatus at each working place. One method is as follows. A card, about 6 inches × 4 inches (e.g. a card-index file card), is placed beside each experiment. The card gives this information:

(i) the number of the experiment in the sequence;
(ii) the name or purpose of the experiment;

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[1] A density bottle which has contained methylated spirits or glycerine can easily be washed clean with water only.

(iii) a brief description of what is to be done;
(iv) a note of what precautions are to be taken;
(v) instructions as to how the results are to be tabulated, or on what has to be observed and drawn;
(vi) any question which will help the student to arrive at some reasonable conclusion.

Figure 13 shows two sample instruction cards, and others will be found in Appendix D.I, page 298. The amount to be written on each card will vary considerably, and will depend on the nature of the experiment, the intelligence of the class, and the stage at which the latter happens to be in its studies. Too much information may encourage laziness and lead to confusion; too little may cause bewilderment, and the teacher's time will be too fully occupied in answering individual questions. Between 'too much' and 'too little' there is some reasonable compromise.

It must not be supposed that this method of setting out experiments can be applied to all practical work, nor that the amount of detail given, and the guidance provided to help the pupil in tabulating his results, are always necessary or desirable. As a general rule, the *minimum* instructions, appropriate to the level of intelligence and skill of the class, should be given. For instance, in the case of experiment ONE above, the reactions of pupils will vary. Some will help themselves to a retort stand and clamp, suspend the spring balance from it, and carry on with the experiment. Others will try to hold the spring balance in the hand, and a wobbling index will make it difficult to read the scale. This is where the teacher needs to be on the spot. Some, whose ingenuity marks them as promising pupils, will suspend the balance from the projecting end of a pencil held flat on a nearby shelf. Others will dumbly look at the balance and wait for someone to suggest some means of suspending it.

Among pupils of such varying intelligence and aptitude the teacher can do his most valuable work, suggesting and advising, encouraging them especially to match their minds to the problem before them, and emphasizing constantly the need for accuracy, tidiness, application and ingenuity. The teacher will find that the more nearly his practical classes come to being a veritable hive of intelligently directed activity, the less frequently will problems of discipline occur.

EXPT. 1. To find the density of a rectangular bar magnet

Apparatus: Bar magnet, spring balance, ruler, thread.

Method: Find dimensions using a ruler.
Calculate volume.
Find weight using the spring balance.
Calculate density.

In note-book write number and title of expt.
Leave ten blank lines and then record measurements and calculations thus:

Length of bar =
Width ,, ,, =
Thickness ,, ,, =
VOLUME of BAR =

WEIGHT of BAR =

∴ *Density of bar* =

In space left blank write an exact description, in order, of how the experiment was carried out.

(*a*)

EXPT. 2. To find the density of a glass bottle stopper

Apparatus: Glass stopper, spring balance, beaker of water, thread.

Method: Suspend from spring balance.
Note weight in air.
Find weight when suspended in water.
Calculate upward thrust.
Calculate volume.
Calculate density.

In note-book write number and title of expt.
Leave ten blank lines and then record measurements and calculations thus:

WEIGHT in air =
Weight in water =

∴ Upward thrust =
∴ *VOLUME* =

∴ *Density* =

In space left blank write an exact description, in order, of how the experiment was carried out.

(*b*)

FIGURE 13.—Two examples of instruction cards—for experiments on density (see Appendix D, page 298, for further specimens)

To the question 'What shall we do with the apparatus when we have finished the experiment?' the most usual answer will be: 'Leave it exactly where and how you found it.' If apparatus is to be put away, it is best to have the materials collected on the bench near the appropriate drawer or cupboard. The teacher is then able to check the materials quickly and see that everything is as it should be before it is put out of sight. Whatever happens, the laboratory should never be left untidy by any class.

(B) *To examine the action of saliva on starch*—This is an example of the third method (page 100) of distributing experimental work among the members of a class.

The following suggestions show how different problems may be set to each group in a class, the information obtained being brought together and summarized in a lesson of the lecture type.

The teacher must keep clearly in his mind from the start the facts which he wishes the class to learn. The summary, which is for the class the climax of the series of experiments, is, for the teacher, the starting-off point in his preparation.

The main facts about starch digestion may be summarized thus:

i. Starch is changed by saliva.
ii. Starch is not changed by boiled saliva.
iii. Saliva acts best in slightly alkaline solution.
iv. Saliva acts most effectively at about body temperature (98° F. = 37° C.).

To demonstrate these four matters suitable experiments must be devised. As there may not be time for each pupil to carry out the whole series of experiments, the work has to be shared among the class. The teacher, having thought out his scheme for practical work, may prepare instruction cards.

(*a*) The starch may be obtained as wheat, or potato, starch, or it may be obtained from local grains or roots. Starch solution for the experiments is made according to the method given in Chapter XI, page 268. The solution is divided among a number of test-tubes, which can be labelled A_1, A_2, A_3, etc.

(*b*) Saliva may be obtained by going through the motions of chewing, or by chewing a clean piece of rubber for a minute. If the mouth is then rinsed out with some warm water, its contents can be emptied into a beaker. The solution of saliva is divided among a number of test-tubes, which can be labelled B_1, B_2, B_3, etc.

(*c*) The distinguishing test for the presence of starch is the addition of a drop of very dilute iodine solution (see Chapter XI, page 267).

Questions: 1. Is starch changed by the action of saliva?
2. Is starch changed by the action of boiled saliva?
3. Does saliva act best in acid or alkaline solution?
4. At what temperature is starch most readily affected by saliva?

Details of the series of experiments devised for finding the answers to these questions are given in the typical instruction cards in Appendix D.I (3), pages 298–303.

The procedure emphasizes two important points:

(i) The method of altering only *one condition* at a time, e.g. in the first experiment, the only variable is the *time*.

(ii) The use of a *control experiment*—e.g. in the same example the starch does not change merely because of lapse of time.

Once the method of organizing a series of experiments is grasped by a teacher, and subsequently by a class, it is possible to arrange almost identical series of experiments designed to answer many problems such as the following:

(i) What is the effect of diastase on starch, and under what conditions is the action most effective?

(ii) What is the effect of liquor pepticus on proteins, and under what conditions is it most effective? (It is convenient to use egg albumen and liquor pepticus.)

(iii) What is the action of rennet on milk, and under what circumstances does it take place?

How many of these sets of experiments should be carried out by the class, and how many demonstrated, must be decided by the teacher himself, taking into account the time available, and the possibility of the class becoming bored if the inquiries are unduly prolonged.

(C) The two experiments which follow show how a group method can be applied to a single problem. It is sometimes possible, while a class is working at set problems, to organize an experiment which will occupy each pupil in turn for one or two minutes only, thus not unduly disturbing his main lesson task. A saving in time and materials results.

(*a*) *To demonstrate how an amoeba moves*—An amoeba is focussed under a microscope, by the side of which is a pile of 6-inch × 4-inch blank papers, numbered in sequence. One pupil can be deputed to look after the experiment, to call his fellow pupils one by one, and to see that the sketches are made on the numbered sheets in order. Pupils go one at a time to look through the microscope and make a sketch of the amoeba. Each pupil makes his sketch on the sheet next in order. Towards the end of the lesson the teacher makes a series of drawings, all about the same size, on the blackboard, reproducing in turn the sketches which the pupils themselves have made. The movement of the pseudopods will then become obvious, and each pupil will have made some contribution to the demonstration.

(*b*) *To make a cooling curve for naphthalene*—The usual apparatus for demonstrating the melting and solidifying point for naphthalene is set up. A large piece of square-ruled paper is placed by the side of the apparatus, which is put in the charge of one pupil. At the beginning of the lesson the apparatus is warmed so that the naphthalene is a few degrees above the melting point: it is then allowed to begin cooling. Each pupil is called upon in turn to leave his other work for a minute or two in order to examine the apparatus, and plot the time and temperature upon the approximately scaled paper. At the end of the lesson, by the co-operation of the class, a bold, large-scale cooling curve has been drawn, from which the melting point of naphthalene can be clearly seen.

THE 'UNIT' OR 'PROJECT' METHOD

The reasons which lie behind the 'unit' or 'project' method of approach have already been mentioned in Chapter IV. The method has various advantages. (*a*) It will tend, provided the theme has been wisely chosen, to focus attention on matters of interest to the pupil, of use to the community and of scientific importance. The interest is spontaneous, not due to deliberate effort on the part of the teacher. (*b*) Tasks are provided, within the framework of the same scheme, for pupils of different tastes and aptitudes. (*c*) Scientists, in common with other people, have a tendency to view their problems from the standpoint of their own interests. A project helps to widen the mental horizon of the pupil. He begins to see that many other matters, besides those of purely scientific interest, are involved when scientific knowledge is used to benefit a community. Local habits and prejudices have to be overcome: individuals, families, tribes and communities may even have to give up their long-established claims to land and natural resources. If these personal and community affairs are ignored, if attempts are made to ride rough-shod over local habits and prejudices, the most costly schemes, inaugurated with the best intentions, may fail in their purpose. Members of a community must be persuaded to co-operate in the application of new and improved methods. Their mental horizons must be widened, so that they may be prepared to agree to the sacrifices and adjustments that large-scale schemes usually involve. The school is the natural place in which to begin to enlighten the community as to what is involved in the application of scientific methods. The science teacher whose vision of his task is so restricted that he is content to ignore these wider issues is failing in his duty, not only as a teacher but as a responsible member of the community.

Planning and carrying out 'units' and 'projects' involves much more work on the part of the teacher than the customary routine of uninspired science lessons. Natural lassitude and indolence can soon overcome original enthusiasm. The teacher should be alert and well informed. He should be constantly accumulating a collection of teaching material in the form of papers, illustrations, articles, reports, and exhibits. He must be able to direct his pupils to the information they seek. He must co-operate with the other teachers in the school, so that all the work of the class may be co-ordinated and correlated. And when a unit of work has been completed, he should be capable of displaying the material adequately for inspection by other classes or by the public: so that with some explanation the lessons to be drawn from the task may be understood even by those who are illiterate.

Some diffident teachers, aware of their ignorance (a very healthy state of mind) of the by-ways of knowledge into which the method is apt to lead, fear to stray outside the well-defined subject-matter of the accustomed text-books. They must be encouraged in two ways. School authorities should understand that suitable illustrated science magazines, teachers' journals, visual aids and the like, are as much a part of class apparatus as blackboard and chalk. Then the teachers themselves need reminding that their function is to teach, and that the lessons of one who has himself ceased to learn are likely to be dull and ineffective. Teachers are not required, except by the ignorant, to be walking encyclopaedias. A teacher's ability soon comes to be respected by his class, and his 'prestige' to be enhanced, when he admits that he does not know all the answers, but proves that he is expert at finding them out.

The whole of a syllabus, especially for the more advanced classes, cannot well be included in a collection of projects or units. Class time is usually not sufficient, and there must be a certain amount of formal instruction to fill the gaps. The pupil should be familiar with some scientific data not readily included in such schemes, and yet essential in any course which aims at providing a rational system of knowledge.

Examples of the 'project' method

(A) A HYDRO-ELECTRIC SCHEME

The teacher's guide	*Pupils' activities*
Lessons on electro-magnetic induction (see pages 88–92)	Making model electric motor
	Visit to electric generating station Making a chart of local supply (if any) Drawing map to show situation of industrial plants (if any) with main cables; areas inadequately supplied
Advantages of electricity: Light easily switched on or off, not blown out by the wind like oil-lamps and candles; Clean, no smoke or fumes; safe, no naked flames;	
Numerous uses—refrigerators lathes drills saws printing machinery, etc.	List of uses to be developed during discussion in class

Sources of power

The teacher's guide	*Pupils' activities*
What drives the dynamos?	Collecting pictures of electrical machinery from magazines, trade journals, newspapers and advertisements
Power from engines driven by petrol or oil	Compiling scrap-books
Power from steam engines—using coal, coke, peat, etc.	Study of local maps showing mineral resources
Are local supplies of these fuels available, or are all imported?	
What other sources of power are there?— Wind, tides, water	Description of local examples
Cost of natural power nothing, but dams, machinery, etc., are very expensive	Making model water wheel and windmill
Are any large-scale schemes in operation elsewhere?	Consulting geographical magazines, books of popular science and engineering, books on special schemes, etc.

The proposed local scheme

Where is it to be? Why? How far from main towns and industrial plants?	Preparation of: (*a*) small-scale maps showing— course of river, proposed site, distances from important towns, etc. (*b*) large-scale maps showing— contours area for proposed artificial lake, if any rainfall
Is water supply likely to be constant throughout the year? One or two monsoons? Rainy seasons? River source in snow-capped mountains? Why is the last an advantage?	(*c*) large-scale map of proposed lake on squared paper; calculation of approximate area
Must any villages be evacuated?	

The proposed local scheme (continued)

The teacher's guide	*Pupils' activities*
What plans are there for new villages or lands for inhabitants?	
Is it proposed to use some of the water for irrigation?	
What crops are to be grown? Are these for home use or for export?	Examining Government reports, etc., to find what food, if any, is imported or exported
How many more families will the new areas support?	

Industries

A hydro-electric scheme is so costly that unless it can produce a great amount of current for profitable use it will be a waste of money.

The teacher's guide	*Pupils' activities*
What towns might be supplied?	
Are there proposals for developing new industries? What industries?	Reading of newspapers, Government publications, etc., on the subject
Are there local raw materials?	Writing a summary of the arguments for and against the scheme
Will there be a demand for the products?	
Can they be made at a reasonable price?	

Transport

The teacher's guide	*Pupils' activities*
How are these products to be transported— to other parts of the country? to markets outside the country?	
Is proposed site easy of access? Mountains, rivers to be crossed? What roads, railways, water-ways exist?	On a relief map suggesting a route for a new road or railway Explaining the choice of route Construction of models
What roads or railways must be built?	
Will new ports or docks have to be constructed?	

Materials needed

The teacher's guide	*Pupils' activities*
For railways: Rails, sleepers or ties Locomotives, wagons For roads: Trucks and cars For docks: Tugs and barges Water supply Coal or oil fuel supplies Cranes, etc.	Detailed lists to be developed during discussion in class
For making all these: steel, timber, tar, cement, cement mixing machines, excavators, bull-dozers, cranes, etc.	Collecting pictures of heavy machines at work Construction of models

The many people employed

What will they need?— Houses Food Schools	Listing of the equipment and furniture in the classroom and estimating their cost
Hospital Bank	Visit to local hospital—the doctor can be asked to show stores and equipment
Men required include: Railway engineers Dock engineers Road engineers Building contractors Water engineers Mechanical engineers Electrical engineers Skilled craftsmen in all trades—plumbers, fitters, electricians, mechanics, masons, carpenters Labourers	Obtain list during class discussion Consult books, articles, pictures, films, etc.
Shopkeepers Teachers Doctors and nurses Clerks, overseers	Visits to, or from, engineers; inquiries about their work

Special machinery required

The teacher's guide	*Pupils' activities*
Electrical machinery Pylons and wire cables Distribution gear Transformers	
Technical matters	
How is current carried? Lessons on conductors and non-conductors; Ohm's law	Various exercises involving simple calculations
Why does current not leak away? Non-conductors and insulators	Collecting various types of insulators
What size cables? Lesson on voltages Use of transformers	
How much current? Meaning of 'watts'	Calculating amount of current used in a house, or school, and its cost
Is electricity dangerous? Precautions in use of electricity in houses	Preparing a list of instructions and warnings that should be given to anyone in whose house electricity is installed
Earthing a wiring system Three-pin plugs	
Economics	
What is the expected cost of the scheme? Where is the money to be found?	Discussion: How does a country manage to: (*a*) save money? (*b*) borrow money?
Money to be saved, raised by additional taxation; how?	
Examination of Government's annual budget	Finding out details of Government loans and Savings Banks:—rates of interest Discussing whether pupils would be prepared to lend money if they had any

Note—Models are often an important and instructive feature of a 'project'. It should be remembered that the emphasis must lie on the scientific principles involved rather than on technical details. This means that models can often be constructed simply, as they should be, by pupils at this stage of schooling.

(B) *The coming of Man on the earth*—A very stimulating sequence of material for a 'unit' with more biological bias was developed in New York State. The list of topics within the unit is as follows:

The birth of the solar system
The changing earth
Plants that are not green
Green plant and animal life begin on the Earth
The development of plant life—
  Green plants, liverworts, mosses and ferns
  Flowering green plants
  New plants and animals
The development of animal life—
  Corals and jellyfishes
  The age of fishes
  The first land animals, the amphibians
  The rise and fall of reptiles
  Birds
  The mammals
  The coming of man

Into such a scheme the teacher can arrange the elementary facts already known to the class, together with additional knowledge appropriate to the pupils' ages and development. It is useful rather as a guide to the teacher than as a syllabus that can be immediately applied.

(C) *Summary of a 'unit' designed to cover the elements of dynamics*

Force—Anything that can be measured by a spring balance (tension or compression) is a force, whether it is the pull of a weight, a spring, or a rope; or the push of a spring, a rod, or the wind, and so on.
Work—Work is done when a force is exerted through a distance. The product of the force and distance moved (in the direction of

action of the force) is a measure of the work done. In the use of a lever a force is applied through a certain distance in order to produce another force acting through a different distance. Assuming that there is no loss of energy in the process, the amount of work put into the job is equal to the amount of work got out. This principle can be applied to the use of pulleys, cranks and windlasses, wheels and axles, screws, gears, hydraulic presses and brakes, etc., and extended to include the inclined plane, etc. The *velocity ratio* of the device is the ratio of the distance the first force moves to the distance the second force is moved.

The work done when a person climbs stairs, or when water is pumped up a hillside, is the total weight of the object (as might be measured by a spring balance) multiplied by the difference in height between the horizontal levels through which the weight has been moved. It makes no difference whether the route taken be long or short, provided that energy is used only to overcome weight and that there are no other hindrances to movement.

When a force is moved and work is done, a certain amount of opposition is met. This opposing force may be due to the downward pull of the earth (gravity), or it may be caused by *friction*. In the latter case energy is 'wasted' by being turned into heat. The only law about friction that needs to be known is that it always opposes motion. The use of tyre treads, brake linings on cars, brake blocks on bicycles, spikes on the soles of running shoes, all illustrate methods of *increasing* friction deliberately. In other instances the need to *reduce* it to a minimum is so important that it can hardly be over-emphasized. Reduction of friction makes machines more effective (*efficient*). The devices in common use include: ball-bearings, pointed bearings, various types of suspension, and above all the use of oil or grease between surfaces that are moving in contact and relative to one another. If two wheels, one large and the other small, both have hubs and axles of the same size, then for the same forward movement of the rim the hub of the larger wheel moves around the axle a less distance than the hub of the smaller wheel. In general, the movement of the hub relative to the axle becomes less as the size of the wheel increases. The very large wheels of Indian bullock carts provide an example of the use of this fact to reduce energy losses due to friction between hub and axle.

There are many reasons why machines lose energy: for instance, by overcoming friction; by overcoming the resistance of air or water; on account of the weight of their moving parts; because they often have to work within certain limits of temperature (e.g. car engines), or under restrictions as to maximum size (e.g. locomotives). The amount of work got out of a machine is therefore always less than the amount of work put in.

The ratio $\frac{\text{work got out}}{\text{work put in}}$ is the *efficiency* of the machine.

(This ratio is commonly expressed as a percentage rather than as a fraction.)

One of the fundamental 'laws' of science is that energy can neither be created nor destroyed. It is called the '*law of conservation of energy*'. Because every machine loses energy for one reason or another, no machine, once started, will go on and on for ever without drawing on additional supplies of energy. Not until the 'law' is proved to have an exception is there any prospect of inventing a machine which will show 'perpetual motion'.

THE TEACHER OUTSIDE THE CLASSROOM

A teacher has not finished his job just because the bell has sounded the end of his last teaching period for the day. Like doctors, teachers are never really off duty. Some lessons can never be taught during ordinary school hours, so the teacher must make use of any chance opportunity that offers. An example of the sort of instruction that may begin quite casually, during out-of-school hours, is a lesson on the apparent motions of the stars.

The vast and confusing number of stars visible on a clear night makes it difficult for a student to note their movement across the sky. Unless the obvious constellations are pointed out to him he has no points of reference from which to gauge the movement. In the northern hemisphere two stars belonging to the Great Bear (Ursa Major) constantly 'point' to the Pole star, and are very useful for reference; but in the tropics they are only visible in the evening sky during a part of the year. Near the equator, Orion (from November to April), the Southern Cross (from March to July), and the Scorpion, like a great letter 'S' drawn across the sky (from April to September), are visible in the evening sky and are easy to identify. In the southern hemisphere, the Southern Cross (from February to August), and the stars Canopus (from November to April) and Achernar (from September to February), provide easily recognizable points of reference.

A casual lesson in astronomy—A teacher has his best opportunity of starting to teach elementary astronomy when accompanying his class during the evening, perhaps across the school grounds to the dining-hall or an evening preparation class, or when he is engaged in some other regular daily or weekly evening activity. This is the kind of conversation that may take place:—

TEACHER: 'The sky is very clear tonight, isn't it?'
PUPILS: 'Yes, Sir.'
TEACHER: 'Do you see that bright star there?' (Pointing—but unfortunately he cannot be seen in the darkness!)
PUPILS: 'Which one, Sir?'
TEACHER: 'If you stand on this step and look towards the near corner of the dormitory roof, you will see it. You can make sure which it is because there are two other smaller stars, close together, slightly to the right of it. Now do you see which one I mean?'
PUPILS: 'Yes, Sir. We see it.'
TEACHER: 'What time is it?'
PUPILS: 'Sir, it is just seven o'clock.'

The talk is continued later that same evening:—

TEACHER: 'Look at that star now. Can you see it?'
PUPILS: 'No . . . Yes, Sir, we see it. But it has moved.'
TEACHER: 'Which way has it moved?'
PUPILS: 'Sir, it has moved towards the west.'
TEACHER: 'What time is it now?'
PUPILS: 'Nine o'clock, Sir.'
TEACHER: 'Yes. You see, the stars seem to move across the sky, in the same way as the sun and the moon.'

Perhaps a fortnight later, there is further discussion:—

TEACHER: 'Do you remember that star we noticed two weeks ago?'

PUPILS: 'Yes, Sir.'

TEACHER: 'Look for it now. Do you see it?'

PUPILS: 'Yes, Sir.'

TEACHER: 'What time is it?'

PUPILS: 'Just seven o'clock, Sir.'

TEACHER: 'Is it exactly where it was at seven o'clock two weeks ago? Stand on this step again, and look towards the corner of the dormitory roof. Well, where is it?'

PUPILS: 'It is farther west than it was last time.'

TEACHER: 'Then, although it is again seven o'clock, the position of the star has moved to the west.'

In this way the teacher has been able to demonstrate not only the apparent movement of the stars from east to west during each night, but also the fact that they seem to move west by about one degree each successive day. Even if the teacher can only identify this one star in the sky, even if he cannot name it, the observations are well worth making.

The movement of a planet relative to the stars is another phenomenon which can easily be watched. The star is pointed out to a group of boys during an evening. Its position is noted relative to other stars near it:—

TEACHER: 'Do you see that bright star, shining steadily?'

PUPILS: 'Which star, Sir?'

TEACHER: 'If you stand in this doorway you will see it just above the left corner of the headmaster's house. It is quite near two bright stars, one to the left of it and the other below it. They make a right-angle. Now do you see it?'

PUPILS: 'Yes, Sir.'

About a week later the 'lesson' goes on:—

TEACHER: 'Can you see the star I pointed out last week?'

PUPILS: 'Yes, Sir. But it seems to have moved away from the spot where it was last time. The three stars do not make a right-angle now. The one that was on the corner of the right-angle seems to have moved away to the right. Sir, why is this?'

TEACHER: 'The star that seems to have moved is really a planet. It is part of our little solar system and is very much nearer than the other stars. It is called a planet because it "wanders" . . . that is the meaning of the word "planet".'

PUPILS: 'Sir, which planet is it?'

TEACHER: 'I think it is Jupiter, but we had better look it up in *Whitaker's Almanack*.'

PUPILS: 'Sir, where should we look in the sky for planets? Are any of these other stars really planets?'

TEACHER: 'No. Planets are always seen somewhere along the path that the sun seems to follow across the sky by day. Only five of the bright stars are planets, and usually not more than two or three are visible at one time, and never more than three can be seen between nine o'clock in the evening and three o'clock the next morning.'

PUPILS: 'Why, Sir?'

TEACHER: 'I shall try to explain it during our next science lesson.'

CHAPTER VII

Some of the Pupils' Difficulties

Pupils must keep some records of their work, whatever modes of instruction the teacher may adopt. It is advisable, then, for the teacher to make up his mind about the methods of note-taking to be recommended to his class. He must also decide upon the most suitable treatment of pupils' misunderstandings and mistakes.

It is the purpose of this chapter to discuss some of the difficulties and problems which a teacher may encounter.

Pupils' notes

Pupils' notes contain descriptions and results of practical work, matter on which the teacher wishes to lay special emphasis, and material which is supplementary to the text-book. There are two alternative methods for keeping these records.

(*a*) The notes are written in a 'rough' note-book and copied later, during private study periods, into a 'neat' exercise book. The advantages of making a second copy are these:

i. If the pupil's handwriting, at speed, is bad, his second copy, given enough time, can be more presentable as a permanent record of instruction received or work done.

ii. Writing out the work a second time helps to fix it in the pupil's mind.

iii. Diagrams can be drawn and labelled carefully.

iv. It ensures that the pupil has something to do during undirected periods of private study.

On the other hand, an original 'rough' record tends to be poor in quality when it is regarded as something temporary which will be scrapped later on. There is a tendency for original records to be made upon odds and ends of paper which are sometimes lost before copying out.

(*b*) The second method is to make one record only. Its advantages are:

i. The pupil takes more care in its preparation.

ii. Because it is the original record, it is 'nearer' to the actual experiment and less subject to the 'editing' of observations and measurements in which the immature student may unwisely indulge. On the other hand it is claimed that reasonably presentable original records take up too much class time.

Taking all the arguments into consideration it seems that one original record, not perfect perhaps, but reasonably kept, is preferable to a 'rough' original superseded by a second, 'neat' copy. It is recommended, then, that the description of an experiment, and the records of the results obtained, should be written up, and the illustrating diagrams drawn, in the laboratory at the time of the experiment.

One note-book should be used both for class notes and for records of practical work. When practical exercises immediately precede or follow the lessons, class notes and records of practical work should follow in sequence. When the practical work is organized so that a group of experiments follows lessons on a small section of the syllabus, the class notes can be entered at one end of the book, and the book reversed and the records of practical work written at the other end. It is, of course, most desirable that all the General Science in any one class should be taught by one teacher. If, unfortunately, this proves to be impossible, then the recommendation that there be one note-book only may have to be modified. One generalization still holds good: the number of note-books used for General Science at any one time should be reduced to a minimum.

The criticism that the writing of original records in class takes too much time may be partly met in two ways. First, the amount of note-taking may be reduced. Provided that a suitable text-book is available, a note-book is a supplement to it, not a substitute for it. The teacher who finds himself dictating, or writing on the blackboard, lengthy notes for the pupils to copy, is probably wasting the time of his class. If he is making summaries, perhaps they are not sufficiently concise; but in any case there is no point in writing out, in class, material which may be printed more clearly, and set out more accurately, in a text-book. The second, and more profitable, way of saving time is to train pupils to draw neat diagrams quickly. This art is of the utmost value to the student at all times, not least during examinations. He gets little practice at it if he has a second note-book into which he copies original material at a pace dictated by his own fancy. Constant practice under the immediate supervision of a teacher, with speed and neatness both emphasized, is the only way to achieve proficiency.

The drawing of diagrams

Before the pupil begins to draw an apparatus, he should be trained to see how the diagram involves a number of straight lines which should be drawn in groups of parallels. He should next be shown how to put in the necessary curves (by free-hand if they are small), and to shade in corks. Then, with a ruler, he should indicate the

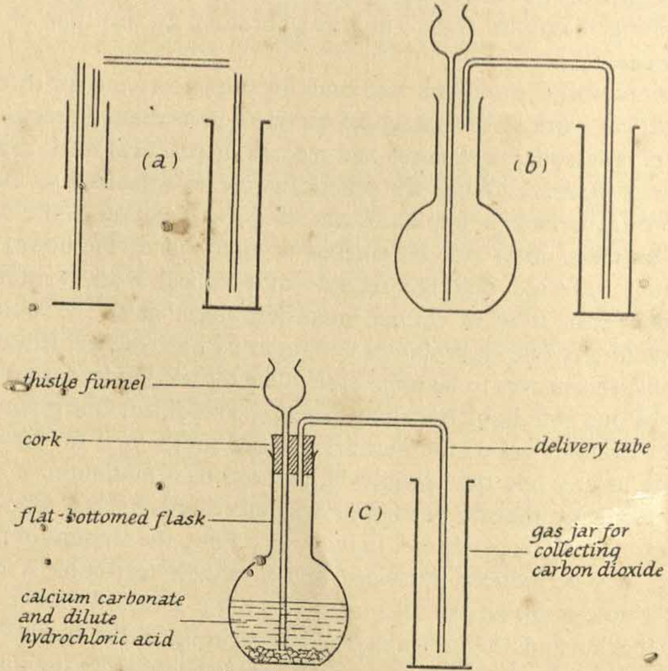
(a)
(b)
thistle funnel
cork
delivery tube
flat-bottomed flask
(C)
gas jar for collecting carbon dioxide
calcium carbonate and dilute hydrochloric acid

FIGURE 14.—The stages in drawing a diagram
(*a*) Straight lines, (first stage)
(*b*) Curves added (second stage)
(*c*) Corks, etc., and 'labels' added (final stage)

presence of liquids by a series of parallel strokes. Finally the diagram should be labelled with descriptions written horizontally. A mnemonic to help remember the order of drawing is: *straight lines, curves and corks.* Figure 14 shows the stages in the drawing of a flask fitted with a thistle funnel and a delivery tube for collecting a gas by downward displacement of air.

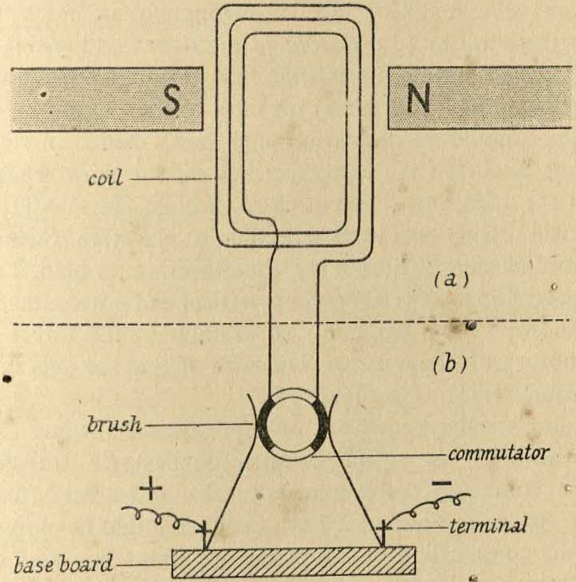

FIGURE 15.—Horizontal and vertical sections in one diagram: an electric motor

(*a*) PLAN—armature and field magnet
(*b*) END ELEVATION—commutator and brushes

Though at first it may be useful to draw retort, burette and funnel stands, even tripods, all these can later be omitted from a diagram, with a consequent saving in time. Their use can often be assumed, and their representation does not usually make the diagram (nor the purpose of the apparatus) any clearer.

The labelling of the diagram should be done in script, not running hand. This makes for clarity and neatness. Pupils need not all use the same script, but each pupil, when he has adapted or adopted a script for his own use, should use it always. An example of a suitable script is shown here:—

a b c d e f g h i j k l m n o p q r s t u v w x y z
ABCDEFGHIJKLMNOPQRSTUVWXYZ

Diagrams should not be labelled throughout in block capitals, although these are to be preferred to ordinary handwriting.

The lettering should be horizontal, thin or dotted lines (horizontal whenever possible) leading from the label to the object.

Diagrams should be drawn in pencil and labelled in ink. They should not be drawn in perspective but should show what would appear if the apparatus were cut clean through the middle. Thus a diagram will usually be a vertical section, or elevation. Occasionally it is more convenient to draw a horizontal section, or plan. There are some pieces of apparatus where both vertical and horizontal sections can be shown in one diagram. An example is the direct current electric motor with commutator. The two different sections should be clearly distinguished as in Figure 15.

There are standard methods of representing various electrical contrivances such as switches, earth connexions, transformers, ammeters, voltmeters, galvanometers, cells, resistances (fixed and variable), etc., as in Figure 16. Each method should be employed as soon as the construction or use of the apparatus has been demonstrated. There are also in common use items of equipment and parts of apparatus for which some standard method of representation is desirable. Such are: burette taps, spring clips, rubber connexions for glass tubing, clamps, bunsen burners, etc. Some recommended conventions for things of this kind are given in Figure 17.

Diagrams which show conditions 'before' and 'after' some action, or process, are often effective. For example, when the volume of an object is found by displacement, two diagrams usefully illustrate what happens when an object is immersed in a measuring cylinder of water (Figure 18).

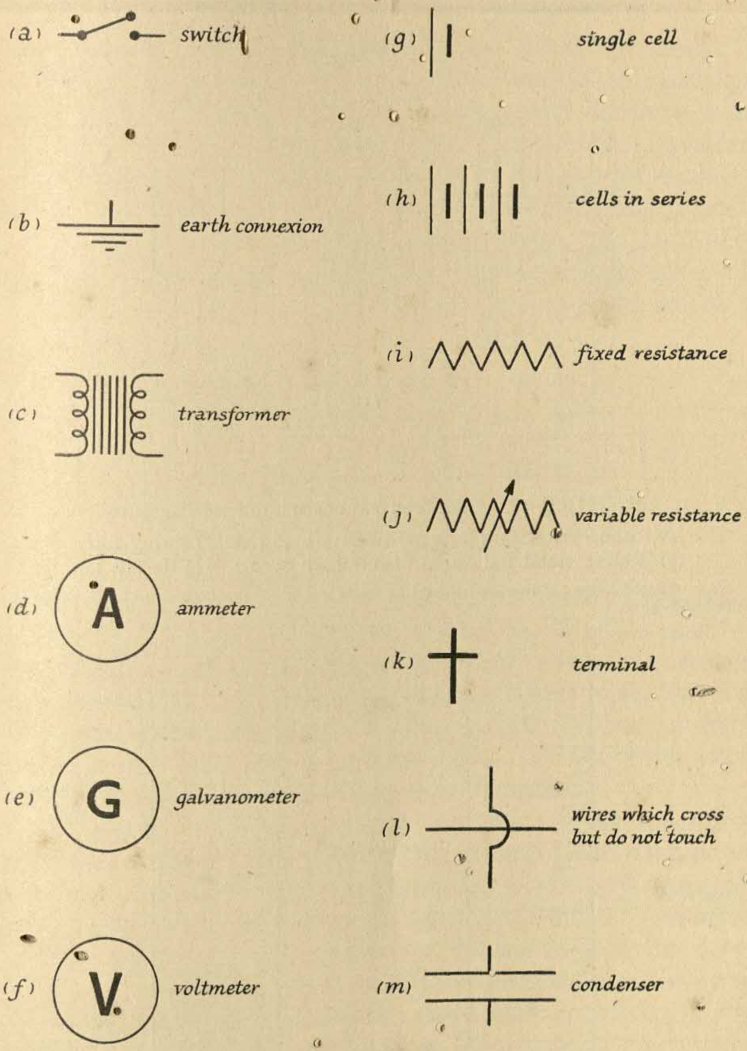

FIGURE 16.—Some conventions for electrical diagrams

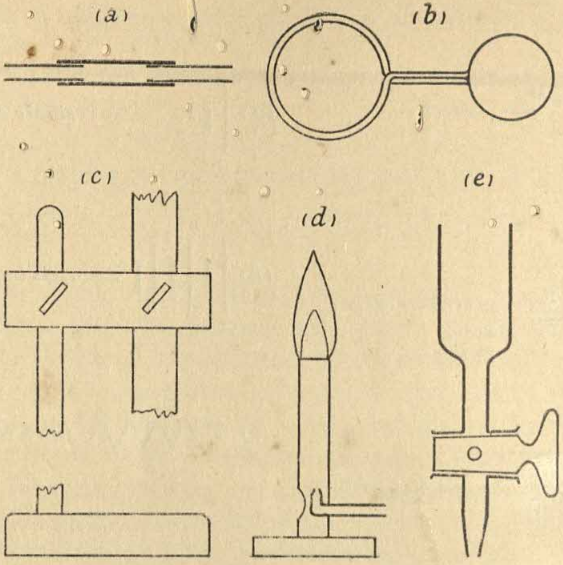

FIGURE 17.—Other conventions suitable for diagrams

(*a*) Rubber connexion for glass tubes (*b*) A (Mohr) spring clip
(*c*) 'Retort' stand and clamp (*d*) Bunsen burner (*e*) Burette tap

Note—Simplifications of this kind should be made and used whenever possible, to encourage speed and clarity.

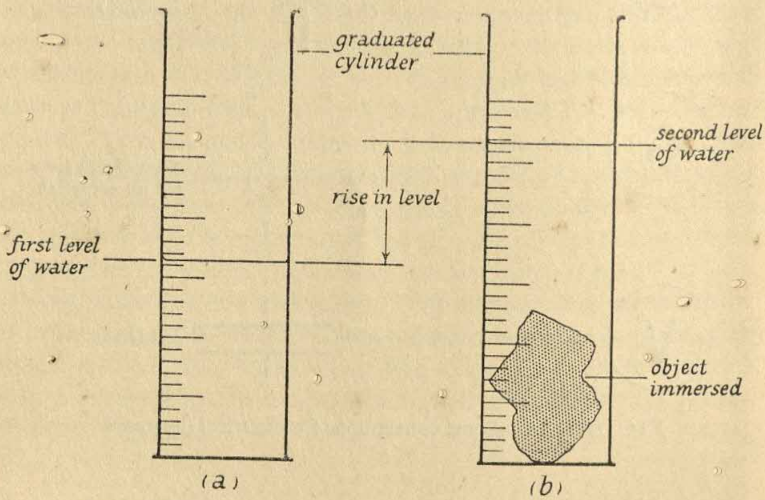

FIGURE 18.—A 'before' (*a*) and 'after' (*b*) type of diagram

Pupils' descriptions of experiments

The order in which the description of an experiment should be written naturally follows the order in which the various operations are carried out. Pupils are apt to include in their descriptions the actual measurements they have made. This should be avoided. Descriptions can be written on one page and the record of results on the opposite page. One page will have, as part of the description, a sentence such as 'I weighed an empty calorimeter. Then I half-filled it with water and weighed it again. I took the temperature of the water. . . .' The other page will have the corresponding record of readings:

Weight of calorimeter empty = 28·2 g
Weight of calorimeter and water = 96·4 g

∴ Weight of water = 68·2 g

Temperature of water = 19·5° C.

The pupil should anticipate the subtraction (to find the weight of the water) and should leave the space in which to fill in the value.

Pupils often like to use special exercise books which have one page ruled and the opposite page either plain or square-ruled. But such books are expensive and by no means essential. A sheet of graph paper can be pasted into an ordinary exercise book on the occasions when a piece of square-ruled paper is needed.

The teacher correcting a pupil's description of an experiment has a great opportunity to encourage the writing of exact descriptions in a simple, straightforward style. The ability to write with clarity is a skill which is of benefit to everyone. The subject matter about which a student of General Science has to write is concrete. It is often easier for him to see faults in style, when these are pointed out to him by his science teacher, than to see similar faults made in writing on less factual subjects. One of the advantages of learning science is that a concise style may be developed, with the material arranged in an orderly manner. The science teacher should see that the opportunity is not missed.

Pupils' descriptive style

Consistency in the use of pronoun and tense should be insisted upon. There is no particular merit attached to any one of the four styles of description which follow:

(*a*) 'I took a beaker half-full of water and placed it upon a piece of gauze resting on a tripod. I heated the water until . . .'

(*b*) 'We took a beaker half-full of water and placed it upon a piece of gauze resting on a tripod. We heated the water until . . .'

(*c*) 'Take a beaker half-full of water and place it upon a piece of gauze resting on a tripod. Heat the water until . . .'

(*d*) 'A beaker half-full of water was placed upon a piece of gauze resting on a tripod. The water was heated until . . .'

Of these four examples the last is the usual style of scientific writing, but it is the hardest for young pupils to use. (*c*) is probably the least desirable, because the pupil should not issue instructions but should describe what he has done. The important thing, however, is for the student to stick to one particular style. Once this has been chosen and he has started his description, he should continue to use the same person, mood, voice and tense.

Pupils' mistakes and their prevention

Some of the many causes of pupils' errors are noted in the following paragraphs.

(*a*) The problem may be misunderstood.

(i) The teacher may have set a problem beyond the ability of the pupil to solve.

(ii) The teacher may have put a question which is badly worded, ambiguous, or too involved. The fault lies with the teacher.

(*b*) The problem may be misunderstood because the pupil is unfamiliar with the terms used. A special case arises when pupils are taught, not in their mother tongue, but in a language with which they are not so familiar. But whether the instruction is in the mother tongue or in a less familiar language, the scientist uses special words, the exact meaning of which has to be learnt. Examples of this class of words are valency, hydrolysis, catalysis, cotyledon, corm, radicle, serrate, axillary, the names of the various families, genera, species, and so on. Confusion is increased when the scientist uses a common word in a special or restricted sense. Examples are period, receptacle, disc, superior (applied to ovaries), inferior (applied to planets), etc.

Here the science teacher adopts the same methods as the teacher of languages uses when he helps pupils to enlarge their vocabulary. Constant practice is given in the use of the words, in spoken or written sentences, and in the filling-in of names in blank sketches, etc. In this way the use of the word 'dissolve' in the place of 'melt', for instance, and of vague phrases instead of the appropriate word, can in time be corrected.

(*c*) The problem may be misunderstood for the simple reason that the pupil is mentally incapable of grasping its meaning. Even equal opportunity does not give students equal ability, and to think critically may be beyond a student's power. The responsibility here lies with those who admit pupils to classes in which they are unable to benefit by the kind of instruction given.

But the lack of understanding is sometimes due to weaknesses which the teacher can help to remove. For example, some pupils seem unable to visualize, from written or verbal instructions, the lay-out of an apparatus. They need plenty of practice in drawing (and later in setting up) apparatus from a simple description, such as: 'A glass tube, about 10 cm. long and 2 cm. internal diameter, is fitted at each end with a one-holed cork. The holes in the corks are not bored centrally, and each is fitted with a piece of narrow glass tubing about 10 cm. long. The two narrow tubes lie side by side for about 2 cm., inside the wider tube.' When necessary a pupil may be helped step by step through an exercise of this kind, and frequent performance of similar work often leads to great improvement. Other pupils sometimes appear incapable of interpreting graphical data. Here again, a great deal of practice often helps: e.g. in reading values from a graph, estimating intermediate points, or finding maximum, minimum or turning points, etc. The teacher can arrange exercises using the curves commonly found in science text-books, e.g. for solubility, cooling, time-velocity, etc., or the statistical graphs to be found in books on economic geography.

(*d*) The pupil may lack the knowledge necessary to come to a correct conclusion. An instance is recorded of a boy whose model electric train would not work. He oiled it, because that is what he did to improve the performance of his clockwork train. He did not know that a battery was required to drive an electric train, so he failed to replace the worn-out battery that was the cause of the trouble. If the class has been reasonably well taught, subsequent questioning and revision will reveal such lack of factual knowledge. These processes in themselves help to provide the knowledge which the pupil lacks.

(*e*) Analogy may be pressed too far. A teacher may rightly use analogy to help a pupil to understand a new idea. Thus atoms may be compared with tiny bricks. If, however, the pupil gains the final impression that atoms are solid lumps of matter, the use of analogy has been overdone. If surface tension is said to cause liquid surfaces to act as though they have a 'skin', it is pressing the analogy too far when the pupil concludes that, in fact, they have a 'skin'. The use of analogy is full of pitfalls for the imaginative teacher and the uncritical child.

(*f*) The pupil may fail to apply the appropriate processes that would yield the correct answer. These failures may occur, for instance, in calculations involving the knowledge of physical laws: e.g. the connexion between the pressure and volume of a gas, the connexion between amperes, volts and ohms in an electric circuit. They may result from failure to understand Archimedes' method for obtaining the volume of an irregular solid and its application in finding the density. Revision, or the repetition of certain lessons, may be called for. There should be more practice with various examples, designed to reduce the arithmetic involved to a minimum. Pupils are otherwise apt to lose the thread of the argument in trying to cope with complicated numbers. In the early stages emphasis *must* be placed on the 'method'.

(*g*) Pupils often fail to see whether an answer is reasonable. Answers may be expressed in the wrong units, or the calculation may be carried to a degree of assumed accuracy which the available data does not justify. Pupils can become so accustomed to examples which are obviously 'manufactured' that their answers are equally remote from reality.

The teacher may need to make a special point of discussing the degree of accuracy to be expected in an answer before the exercise is begun. The help of the teacher of mathematics is useful to ensure that the meaning of 'significant figures' is understood. But the most lasting results can only be obtained when the science teacher brings into the lessons a 'breath of fresh air'; when they are based as far as possible on everyday examples—on real, not manufactured examples; when the results considered are those of actual experiments done in the laboratory; when models, visual aids, and all the devices which are the normal tools of an alert teacher, are brought into use.

Eager pupils often lack self-discipline, and training in this is needed if they are not to rush into doing a calculation or performing an experiment without first attending thoroughly to instructions, both oral and written.

(*h*) It is a common human frailty to draw conclusions from too little evidence. Science students, like others, show this tendency. The following are examples of pupils' conclusions which are INCORRECT because they were too hastily drawn: (i) '*All* compounds of copper are blue because *some* crystalline salts of copper are blue.' (ii) 'Because water is heavier than air, therefore air, with water dissolved in it, is heavier than dry air. (iii) 'A west wind *always* brings rain, because it does so in one particular place.' (iv) '*All* crystals contain water of crystallization because it is present in *some* common ones.' These statements are FALSE.

The teacher must emphasize that the scientist makes 'hypotheses' —he rarely claims to have established the truth of a 'law'—and is wise if he notes deliberately the range of material from which he draws his conclusions.

(*j*) Some children are lazy. No single reason will explain why this is so. If it is because the pupil is bored, then the teacher must improve his methods. But it is sometimes due to the fact that the pupil is not physically fit to study. The responsibility for improving this condition is not mainly the business of the teacher. The teacher, however, because of his close acquaintance with the pupil, has an unequalled opportunity of observing him, and may be able to diagnose the cause. Signs of anaemia, weak eyesight, faulty hearing, should become quickly evident, and it is the duty of the teacher to draw attention to such conditions, and to use whatever means lie in his power to persuade parents, the school authorities, or the community, to take proper steps to remedy them.

(*k*) Misconceptions are hard to dispel. It may be necessary to do an experiment to bring out clearly the real facts. The planning and performance of an experiment for correcting a fallacious idea or removing a misunderstanding is excellent training from every point of view. An example may be found in one quite common difficulty. —Pupils find it hard to believe that the water in the reservoir of the wet bulb of a 'wet and dry bulb thermometer' is not colder than the dry bulb. They attribute the 'coldness' to the water itself and not to the effects of evaporation. Thus it may be necessary: (*a*) to repeat the various simple experiments on the cooling effect of evaporation; (*b*) to show that there is very little direct evaporation from the vessel concerned (a control experiment); and then (*c*) to demonstrate that the water in the reservoir is *not* colder than its surroundings. The last may be done by putting a third thermometer directly into the water. (If this is impossible in the particular reservoir, a small beaker can be substituted for it.)

The treatment of mistakes

The experienced teacher knows the pitfalls which his subject offers to the learner, and may deal with them in two ways. (*a*) He may lead up to the danger point, warn the class of the 'trap' and explain the problem. Then he may hope that the possibility of the class making the error has been averted. (*b*) He may wait for the mistake to be made and then correct it immediately afterwards. If he adopts this course, he should have provided the class with the necessary guidance for making the correct conclusion, and there should be no delay between making the error and making the correction.

Pupils commonly fail to appreciate at first that a complete vibration has only been made when a particle again moves past a given position in the same direction. If the teacher adopts the first method of dealing with mistakes, he may comment particularly on the example of the pendulum bob. If he takes the second attitude, he will not consider the pendulum in particular, but will give examples of other vibrations, e.g. a particle going round in a circle, or the distance between two waves on water, and then leave the students to apply the idea of 'the same direction' to the pendulum. Sometimes pupils are unable to make the connexion between 'the same direction' and the swing of the pendulum, and they count each movement past the lowest position as one vibration. If pupils can apply the principle without too much 'spoon feeding' then they should be given a reasonable opportunity of doing so. It is a poor teaching method which gives the answer to every puzzle in advance, and tries to ensure that nobody can make a mistake—and it is poor training for the larger problems of life outside the laboratory.

The profitable use of spare minutes in class

Pupils do not all work at the same rate. When several different experiments are being done simultaneously in a class, they cannot all be completed in the same length of time, however carefully the teacher may try to arrange for this to happen. Thus, some pupils may find themselves with a little time to spare at the end of a practical lesson. Their work is finished, the teacher is busy supervising and correcting the work of other members of the class, but it is good neither for their general training, nor for discipline, that such time should be wasted. How can the few minutes be used in a manner which leaves the teacher free to give individual attention to other, and maybe slower, members of the class?

Magazines—One method is to let pupils who have finished their other work help themselves to one of a pile of magazines kept in the laboratory. The magazines need not be those of most recent date, which are likely to be in the school library or reading-room. Older magazines will do. Periodicals such as those listed in Appendix F, 6, page 346; magazines for amateurs interested in radio, photography, railways, engineering; bulletins published by government departments or through public relations officers on local forestry, irrigation, mining, agriculture and the like; trade journals, catalogues, etc., are all useful. At the end of the lesson the journals should be returned to their place in the laboratory.

Constructional toys—Another method, useful in encouraging the skilful use of the hands, and in giving the pupil a practical acquaintance with various mechanical devices, is to obtain a large toy constructional set.[1] About eight or ten of the illustrations of simple models are cut out of the instruction books and pasted on separate pieces of cardboard. Each piece of cardboard, with the appropriate selection of pieces (strips, rods, clips, wheels, angle-brackets, nuts and bolts, etc.) is put into a separate box. (Empty blackboard-chalk boxes are useful for this purpose.) A pupil can take one of the boxes and construct the apparatus when his practical exercise is finished. It must be remembered that each of the eight or ten boxes will require a spanner and a screw-driver. These should be obtained, together with additional simple books of instructions, when the original set is bought. Models showing the use of bevel gears, contrate gears, reverse and forward gears, reduction gears, etc., can be constructed. It needs to be emphasized that, for the purpose of filling up the last minutes of a lesson, the models chosen for construction should be very simple, but should illustrate some mechanical principle or device. Complicated models of liners, locomotives, etc., are entirely out of place. The idea can be extended. A collection can consist of an ordinary electric switch, a batten lamp-holder, some wire, some wood screws and a piece of fibre board. The pupil, given a diagram to help him, can then learn how a house lamp and switch are wired up.

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[1] e.g. '*Meccano*'.

'*Quiz*' *cards*—A third individual occupation for the end of a lesson consists in answering 'quiz' cards. Two boxes each contain sets of filing cards numbered in sequence. In the first box each card has about ten questions written on it. In the second box the answers can be found on the card of the same number. The pupil takes one of the 'quiz' cards, returns to his bench, and writes down the answers on a piece of paper. (On no account should he write anything on the 'quiz' card itself.) He then gets the appropriate answer card and compares it with his own list of answers. The student must return both cards to their original places in the boxes, and may then take another 'quiz' card. Questions may be of the most varied kinds, but they should be short, preferably requiring answers of only one word. Examples and some specimen 'quiz' cards are given in Chapter VIII, page 172, and Appendix D. II, page 304.

CHAPTER VIII

Evaluating the Results of Science Teaching

The importance of tests

The purpose of teaching science is not only to instil a knowledge of facts, important as this may be. It is to develop skill in the use of apparatus, to develop skill in critical thinking and an appreciation of scientific methods, to encourage desirable attitudes and interests, and to stir the imagination. The teacher should find out, from time to time, not only how many facts the pupil has managed to remember, but what progress he has made in the development of these other skills and qualities.

It is comparatively easy to discover the amount of factual knowledge gained. Unfortunately, testing is too often limited to such knowledge. The pupil who has a retentive memory is apt to gain much more credit than he would were the whole range of desirable qualities to be taken into consideration. The further a teacher moves from the limited field of objective facts, in an endeavour to test more subjective qualities, attitudes and interests, the more difficult he finds it to make an objective estimate. To the question 'How many legs has a dog?' there is one answer, 'Four legs'. Similarly to the question 'Name six parts of the alimentary canal in order, and summarize, in paragraphs of not more than forty words, the function of each part', the answer admits of little variation. But the worth of an answer to the question 'What would you provide for passengers about to travel by a rocket to the moon?' is much more difficult to assess, by any standard of measurement.

To find out whether a pupil, as a result of his training in the laboratory, has become more co-operative, or more self-reliant, more ready to submit prejudices to the tests of reason, is an entirely different problem from that involved in estimating his knowledge of facts. It must be remembered that 'spiritual truths can only be spiritually discerned'. In the last resort no quality can be adequately represented by a number, a letter, or a percentage. Yet unless certain qualities have in fact been developed the teaching of science has failed in its main purpose.

In order to overcome this fundamental difficulty, various attempts have been made to estimate qualities by dividing each into a number of aspects. By simplifying the analysis it is hoped to obtain a more reliable estimate. For example, to estimate whether a pupil shows increased *sense of responsibility*, the teacher may record his judgement at regular intervals, perhaps two or three times a year. Indications of this quality may be graded:

(*a*)—fulfils his obligations willingly;
(*b*)—usually fulfils his obligations;
(*c*)—avoids his obligations or performs them unwillingly;
(*d*)—constantly avoids obligations.

Again, under the heading '*degree of interest shown*', the pupil's characteristics may be graded:

(*a*)—very keen, asks questions, brings original material to class;
(*b*)—attentive, borrows books from the library, occasionally asks questions, preparation work always done carefully;
(*c*)—no trouble in class, but preparation work careless, rarely asks questions, shows little original interest;
(*d*)—shows no interest, never asks an original question.

It is to be noted that although the range of the quality is analysed into graduated stages, the pupil's position in that grading is still largely a matter of subjective judgement. The fundamental difficulty is not overcome, but the assessment is made a little less haphazard.

Between the easy task of finding out how many facts a pupil has remembered and the hard task of estimating the more elusive but desirable qualities which the course is designed to encourage, there is a range of skills not difficult to test. The degree of manipulative skill acquired by a pupil can be evaluated by practical tests. The degree of attainment in critical thinking can also be tested by appropriately designed questions. Examples of tests for achievement of various kinds are given later in this chapter.

The dull teacher sets a dull examination paper; the teacher gifted with originality produces questions which reflect his own qualities. If a teacher has set the same paper, year after year, to pupils of a certain grade, his pupils may have learned something, but it is certain that he has learned nothing. An examination paper often reveals more about the teacher who sets it than about the pupils who answer it.

The results of a well-designed test disclose the effectiveness of a teacher's work. If results are poor it need not be assumed that the class is composed of dull students. It may be that the teacher himself is dull. The comment 'This pupil takes no interest in his work', may be justifiable, but the teacher may be to blame. He may be equipped with plenty of facts, but unable to 'get it across'. Such a teacher must reconsider his methods, attend refresher courses, discuss his problems with his colleagues, and search teachers' magazines for hints and tips for the more lively and effective presentation of his subject. If pupils' answers to some questions are of much poorer quality than the average for others, he must try to discover the reason and remedy the weakness in his teaching.

Testing can serve other purposes besides the obvious one of evaluating pupils' progress. Upon the results can be built up a diagnosis, and from this some suitable line of treatment can be planned. In the world of medicine a diagnosis, if it discloses a lack, or an irregularity, is followed by remedial action. So the results of testing, if they reveal ignorance or error, should lead to remedial treatment. An excellent educational opportunity is missed if the teacher does not go through the test papers with his class. For with a marked paper before him even the dullest pupil is, for a while, emotionally stimulated, and most likely, therefore, to profit by correction.

General methods of testing

(*a*) *Written examinations*—The usual method of requiring written answers to tests and examinations may be applied to test factual knowledge and the ability to think logically.

(*b*) *Assessment of the pupils' other work*—Original notes should be examined and assessed. The points to be considered are whether (i) the work has been logically set out; (ii) the treatment is adequate (neither too much nor too little); (iii) the work is accurate; (iv) the work is neat. Each aspect should be taken into account. The same qualities can be expected in scrap-book material collected to illustrate a topic, or, indeed, in any original paper work produced by the pupil.

The degree of skill shown in carrying out experiments should be observed. Consistency of results, in a series of repeated experiments, is an indication of the reliability of the pupil's work. The accuracy of the final result may also be regarded as another measure of his skill.

Questions in class

(*a*) *Methods of questioning*—A great deal of class time is taken up by questions put by the teacher and answers given by the pupils, so it is well to know how to question and to understand what purposes questioning can serve. A question must not be ambiguous, and must be clearly stated in words which the pupil understands. If the language of instruction is not the pupils' mother tongue, particular care is needed to make sure that they understand the meanings of the words and phrases used. The use of an unfamiliar language leads pupils to rely on parrot-like repetition of phrases taken indiscriminately from text-books and teachers' notes.

It is best to announce the question before naming the pupil who is selected to answer it. Pupils should not necessarily be questioned in turn in the order in which they sit, or alphabetically, according to their names, lest some pupils lose interest in the intervals between questioning. They should be kept alert, and made to think of every question as it is asked.

It is not wise for a teacher always to indicate at once when a correct answer has been received. When the same question is asked of several pupils in turn, each giving an answer, all these are actively participating in the work of the class. Further, there may emerge from the class, in the end, a more satisfactory answer than any one pupil can give by himself.

(*b*) *Reasons for questioning*—Questions may be asked to find out what pupils know, and what they understand. They may be used at the beginning of a lesson to revise previous work (reminding them of what they are expected to know), and to gather together information that will be of use during the lesson. Questions should be given to draw out knowledge, not to exhibit pupils' ignorance. Except for an occasional revision exercise, when the teacher deliberately chooses questions in any order from a wide field, questions should lead on from point to point, and a logical sequence of thought should be established.

Questions which seek information are good. Questions which disclose a meaning and encourage thought are better. Questions which lead a pupil to determine to find out the answer for himself, or to put his knowledge to practical use, are the most valuable of all.

(*c*) *Short written answers*—A quick revision of a previous lesson can be made in a few minutes. A half-sheet of an exercise-book is all that is needed by each pupil. About ten straightforward questions are asked, each requiring a short answer—preferably of one word—but questions inviting a simple 'yes' or 'no' should be avoided. (In the latter case, guess-work alone is likely to gain half marks for any pupil.) The advantage of this over oral revision, is that every member of the class must try to answer every question. For instance, after lessons on respiration the following questions might be asked:

(1) Name the two gases which compose most of the air.

(2) Which gas takes an active part in respiration? (Because it offers only two alternatives this question is, in fact, little better than a 'yes' or 'no' type.)

(3) What gas is expired in exchange for part of the active gas?

(4) What solution is used to show that breathed-out air is different from air breathed in?

(5) How is this solution changed by breathed-out air?

(6) Name the pores, in the under surface of a leaf, which admit air.

(7) When do plants 'breathe'?

(8) Name the substance, carried by certain blood cells, which has to do with respiration.

(9) What colour is blood (*a*) in the arteries?
(*b*) in the veins?

Papers are exchanged between pupils, who mark each other's answers. Such factual tests are quick and effective, and take little class time. Correct spelling should be insisted upon.

(*d*) *Longer verbal answers*—Questions that demand verbal replies can be framed to require longer answers. For instance, during a lesson on acids and bases the teacher can inquire what liquids, known to the class, are 'sharp' and 'sour'. The answers may provide suggestions that vinegar, sour wine or milk, and fruit juices, especially the juices of immature fruit, are acid. They can be tested with litmus paper. Another question may remind the class that carbon dioxide is acid to litmus; hence the possibility that lime-water is alkaline because it reacts with the gas. A test of lime-water, to see if this is indeed the case, then follows. A question should often lead to some suggestion which may be tested, or followed up, appropriately in that particular lesson or in one very shortly to follow.

The following is the kind of question and answer often heard in a class under the direction of an incompetent teacher:

TEACHER: 'Lime-water is alkaline. What is lime-water?'
CLASS (in chorus): 'Lime-water is alkaline.'
TEACHER (repeating himself): 'What is lime-water?'
CLASS: 'Lime-water is alkaline.'
TEACHER: 'That is right. Lime-water is alkaline.'

In such an exchange of words between teacher and class no additional information has been gained or extracted, no one in the class has been required to think, no suggestion has been made that leads to further inquiry.

(*e*) *Questions for pupils of different abilities*—Class questioning serves to keep a class alert. Some pupils are keen and are ready to answer any questions. They should not be allowed to answer all the questions. The harder ones should be saved up for them, and to provide some 'face-saving' the teacher may well comment that such and such questions are, indeed, difficult. The minds of brighter pupils are thus kept at a stretch, and they are not disheartened if the easy questions are not directed to them. The less able members of the class are provided with questions within their compass and gain some encouragement by being able to answer them.

A question fired at a named pupil whose attention seems to be wavering helps to bring his mind back to the problem in hand. (A teacher should be particularly patient with pupils who stammer. It is wise, if named pupils are asked questions, for stammerers to be asked those which demand only very short answers.)

(*f*) *Pupils' questions*—A variant on the usual question and answer procedure is provided when the questions are suggested by members of the class. At the end of a lesson the class may be invited to suggest the sort of question which the teacher may be expected to ask. These will be mainly questions requiring a knowledge of facts, and will include those requiring the names of parts of insects and plants, for instance, or the names of instruments and apparatus, or chemical or physical formulae, or lists of properties.

(*g*) *Questions invited*—During five minutes at the end of a class period a teacher may invite questions from anyone in the class. If he has gained the confidence of his pupils this part of the lesson may be very profitable indeed. Here the teacher needs tact, so that the pupil who asks an irrelevant question is not snubbed, and patience, so that the pupil who asks a question which shows that he has missed the whole point of a lesson is not too vigorously rebuked. For if the latter has indeed missed the point of the lesson it may be the fault of the teacher. To know which pupils are genuinely dull, which uninterested, which merely malingering and which are genuinely trying to learn but have yet failed to understand, is part of the art of teaching. The teacher with experience becomes almost intuitively aware of the attitudes and abilities of his pupils.

The quality of a pupil is often shown far more by his ability to ask an intelligent question than by his ability to give a correct answer, just as the genius of a scientist lies more often in his selection of the right questions to ask of Nature than in his skill in the pursuit of the answers.

(*h*) *Discussions, conferences and interviews*—In the informal and non-regimented arrangements of the modern classroom, classes can easily assume the form of discussion groups. The problems under discussion may cover a wide range. On one occasion arrangements for the provision of specimens such as frogs, mosquitoes or flowers, for the next lesson, may be dealt with; on another a scheme for the regular cleaning or tidying of the laboratory may be discussed; or a new rota for the regular reading of meteorological instruments or for the care of a garden may be drawn up. There is no hard and fast distinction to be drawn between where an ordinary lesson ends and a discussion group begins. But the function of the teacher changes from director to chairman. The class may be hardly conscious of any change in procedure. During such non-technical discussions the teacher has an opportunity of judging the keenness of pupils from another angle.

A teacher who has a large class has limited opportunities for dealing with individuals. To answer a pupil's question the teacher may have to stray into some scientific by-path. The keenness of the pupil concerned may enable him to make a great effort to follow the teacher's explanation. But the interest of the rest of the class may begin to waver. They may suspect the purity of the motive which has led their classmate to demand such exclusive attention on the part of the teacher. Under such circumstances the teacher may have to await an opportunity of meeting the boy out of class and discussing the matter with him alone.

During a well-organized practical lesson, however, as the teacher moves from one pupil to the next he has an opportunity of answering individual questions and assessing interests and attitudes. He may also see among a pupil's belongings some article—a book, a contrivance, some prized possession—which the pupil may be glad to describe, or explain, or learn more about. In this way the teacher may gain an insight into the depth of individual interest and understanding. At the same time, he may be able to suggest further sources of information or uses, or, by some word of encouragement, warning or advice, to give a permanent bent to the pupil's interests, perhaps his whole future career.

Evaluating general progress

(*a*) A question of the essay type, suitably phrased, may yield some evidence of the development of desired interests and attitudes. Examples are: 'Is the study of science worth while?' 'My favourite subject', 'Which science text-book I like best, and why'. Pupils are apt to write what will please rather than what they really think, so the evidence obtained from reading answers to such questions is not very reliable.

(*b*) The 'atmosphere' of a class may be considered. Do the pupils come to class willingly or reluctantly? At the end of a lesson do they leave the class with an obvious sense of relief, or do they tend to linger regretfully? Do they seek to be excused from attending class on the various pretexts that pupils so readily invent?

(*c*) Does the teacher himself enjoy the lessons? He may be convinced that he is conducting his class well, that his lessons are well prepared, that he is covering the chosen syllabus. All this should, of course, be the case. His class may have a certain amount of entertainment value. It would be inexcusable if certain lessons that the teacher of General Science must give were other than entertaining. But more can be expected than this. The teacher should experience an inner satisfaction after a good lesson; it is likely that the same kind of satisfaction will be felt by a pupil. The experience is subtle and hard to describe, and is similar in this respect to other aesthetic experiences. But the person who has had such an experience knows it, and can testify to its reality. Somehow he knows that he has shared an experience with his class, and this is evidence that some, at least, of his pupils have also entered into it.

(*d*) If the organization of the school permits, the help of pupils may be enlisted in preparing for lessons by setting out experiments, in keeping shelves and cupboards tidy, in renewing labels, and in keeping apparatus clean and in good condition. A teacher can make a fair estimate of a pupil's attitude to the subject, and of the extent to which he has developed a sense of responsibility, by observing his willingness to take his turn in a rota of duties, and by the regularity, or otherwise, of his appearance in the laboratory at the appointed time. In the book in which he records the experiments carried out by each pupil, the individual marks scored in tests, and so on, the teacher can well set aside columns in which to note qualities he has been able to observe. He will, of course, find it easier to note the instances of great helpfulness or obvious indifference than to estimate the intermediate qualities shown by the majority of the class. But incomplete though such records may be they are a help in making a reliable assessment, especially when a pupil is leaving school and wants a testimonial, or when would-be employers are seeking suitable employees. Gradings like those suggested on page 136 may be used under the various headings in the record book.

Written tests

(1) *Short-answer questions*—These require the minimum of writing from the pupil, and thus save time. They may be divided into several types:—

(A) *Logical selection type*—These exercises require the pupil to cross out the name of an object which, not resembling the others, does not fit into the same category. The usual instruction to pupils is;—'Cross out, in the following list, the word which does not seem to belong to the same group as the others.'

Examples: (*a*) horse, crow, cat, mouse.
(*b*) wave-length, frequency, compression, amplitude.
(*c*) pints, litres, grams, cubic centimetres.

(In (*a*) 'crow' is to be crossed out, as the others are mammals. In (*b*) all are connected with wave motion and can be measured in terms of some unit, except 'compression' which merely records a condition and is to be crossed out. In (*c*) all are measurements of volume, except 'grams' which is a measure of weight and is to be crossed out.)

The tests enable the teacher to gauge the pupils' ability to analyse a problem and suggest to themselves various hypotheses until, having hit upon a probable one, they eliminate the item which the hypothesis would exclude. Consider the example in which a student is required to cross out one word from the following: water, mercury, chalk, common salt. A pupil might begin by asking himself 'Is there one solid while the rest are liquid?'—'No, there are two solids, chalk and common salt.' Then, 'Is one used as food while the others are not?'—'No, for both water and common salt are part of a normal diet.' 'Is only one white?'—'No, chalk and salt are both white.' So he goes on, until he notices that mercury is an element, while the rest are compounds, and proceeds to cross it out. (He might also cross it out on the grounds that it is the only metal, or the only good conductor of an electric current.)

In compiling such questions the teacher is able to cover a wide range of facts and is able to introduce concepts which are appropriate to any stage of development.

(B) *Multiple choice type*—The test provides a choice of several possible answers, of which only one is correct. The usual instruction to pupils is:—'Underline the correct answer to each of the following questions.'

Examples: (*a*) The speed of sound in air is: (i) 10 ft. per sec. (ii) 550 ft. per sec. (iii) 1 mile in 5 secs. (iv) 60 miles per hr.

(*b*) A klinostat is used: (i) to show the effect of gravity on the growth of plants; (ii) to measure the distance between successive waves; (iii) to measure the angle between a slope and the horizontal; (iv) to regulate the temperature of an oven.

(*c*) Archimedes lived about: (i) 1000 B.C. (ii) 250 B.C. (iii) A.D. 100 (iv) A.D. 1500.

(The answers to be underlined are: (*a*) '1 mile in 5 secs.'; (*b*) 'to show the effect of gravity on the growth of plants'; (*c*) '250 B.C.')

(C) *Sense discrimination type*—A somewhat more complicated version of the second type of test (B) requires a pupil to select those words and phrases which will combine to form a logical or correct statement. The instruction to pupils is:—'Cross out words or phrases from each group so that a logical or correct statement remains.'

Examples: (*a*) $\text{Acids turn}\left\{\begin{matrix}\text{red}\\ \\ \text{blue}\end{matrix}\right\}\text{litmus}\left\{\begin{matrix}\text{red}\\ \\ \text{blue}\end{matrix}\right.$

(*b*) $\text{When steam reacts with}\left\{\begin{matrix}\text{copper} & \text{hydrogen}\\ \text{magnesium,} & \text{oxygen}\\ \text{silver} & \text{nitrogen}\end{matrix}\right\}\text{is liberated.}$

(*c*) $\text{When an object}\left\{\begin{matrix}\text{floats}\\ \\ \text{sinks}\end{matrix}\right\}\text{in water the}\left\{\begin{matrix}\text{upward thrust}\\ \\ \text{downward thrust}\end{matrix}\right\}$

$\text{is}\left\{\begin{matrix}\text{less than}\\ \text{equal to}\\ \text{more than}\end{matrix}\right\}\text{the weight of the object.}$

(The sentences left should read: (*a*) 'Acids turn blue litmus red.' (*b*) 'When steam reacts with magnesium, hydrogen is liberated.' (*c*)—there are two alternatives—*either*, 'When an object floats in water the upward thrust is equal to the weight of the object,' *or* 'When an object sinks in water the upward thrust is less than the weight of the object.')

(D) *Matching type*—The test requires appropriate words in one column to be matched against corresponding words in another column. The instruction to pupils is:—'Put in front of the letters in the second column, the number of the corresponding word (*or* name, *or* phrase, *or* formula, etc.) in the first column.'

Examples:

(*a*)	(1) Na_2CO_3	( )	(i) Sodium carbonate
	(2) $NaHCO_3$	( )	(ii) Copper sulphate
	(3) $MgCl_2$	( )	(iii) Magnesium chloride
	(4) KNO_3	( )	(iv) Manganese dioxide
	(5) $CuSO_4$	( )	(v) Sodium bicarbonate
	(6) MnO_2	( )	(vi) Potassium nitrate
(*b*)	(1) Starch	( )	(i) Protein
	(2) Butter	( )	(ii) Carbohydrate
	(3) Meat	( )	(iii) Fat

(The correct order of the numbers to be placed in the second column is: (*a*) 1, 5, 3, 6, 2, 4; (*b*) 3, 1, 2.)

(E) *Reasoning type*—The test suggests a variety of possible answers to a question. Of these the pupil is asked to select that which is the most logical. The usual instruction to pupils is:—'Underline the answer which seems to you to be the most reasonable.'

Examples: (*a*) A thick vessel of ordinary glass may crack if you pour poiling water into it because:

(i) thick glass is not strong;
(ii) the careless use of hot water can cause accidents;
(iii) thick glass is expensive;
(iv) thick glass expands unevenly;
(v) water is a poor conductor of heat.

(*b*) An observer only sees a rainbow when he stands with his back turned towards the sun because:

(i) the sun is always shining brightly when a rainbow is seen;
(ii) it is made of many colours;
(iii) there is always rain in the neighbourhood of a rainbow;
(iv) it is formed by light reflected from distant raindrops.

(The answers to be underlined are: (*a*) (iv); (*b*) (iv).)

This type of test is also useful for testing factual knowledge, as in the following example:

(*c*) Ammonia gas is not collected over water because

(i) it is an alkaline gas;
(ii) it is colourless;

(iii) it dissolves readily in water;
(iv) it is lighter than air.
(The answer to be underlined is (iii).)

(F) *Completion type*—This type of test enables a teacher to evaluate a great deal of factual knowledge without much writing by the pupil, who has to fill in blanks left in sentences or lists, etc. The instruction to pupils is simply:—'Fill in the blanks in the following:' Examples: (*a*) The pitch of a note given out by a stretched wire can be raised if the wire is ...., or ...., or ....

(*b*) The .... is a wall of muscle which separates the .... from the abdomen.

(*c*) The common name for potassium nitrate is .... Its chemical formula is .... When it is heated it .... and gives off .... The substance that remains is called .... and often appears slightly .... in colour.

(G) *True or false type*—The pupil is required to say whether the statement is true or false. The usual instruction to pupils is:—'Against each of the following statements, put, in the space provided, a "T" if the statement is true, or an "F" if the statement is false.' Examples: (*a*) Coconut oil is denser than water. ( )

(*b*) Air is light. Therefore the more air one pumps into a tyre the lighter the tyre becomes. ( )

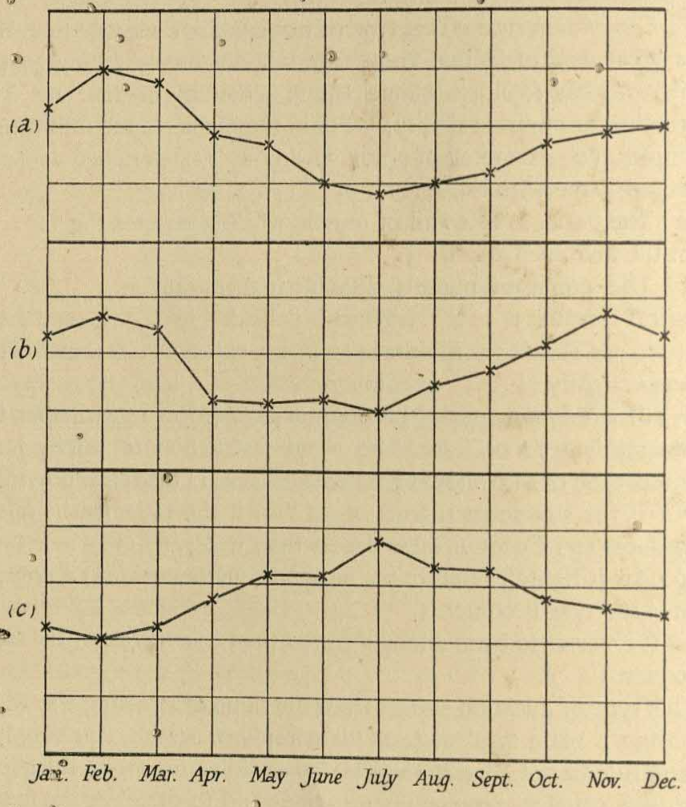
(*c*) It is easier to bend a long iron bar than a short one of the same diameter. ( )

This type of question suffers from the same disadvantage as those requiring a plain 'yes' or 'no' for a reply. Guessing can supply a certain number of correct answers. To avoid giving credit for guesswork it is usual to arrange the questions and to calculate the marks as follows. Equal numbers of true and false statements are provided. In a total of 10 questions 5 correct answers may result if the student merely writes a list of 'T's' or a list of 'F's', so no marks at all are given for 5 correct answers. But 6 correct answers score 2 marks, 7 score 4, 8 score 6, 9 score 8, and all answers correct score the full marks, 10. It is not always easy to convince a dull class that such a method of estimating marks is just!

It is often better to develop the 'true or false' type of question, as in the following examples:—

1. The accompanying graphs were obtained from figures for a

certain town, showing (*a*) death rate, (*b*) rainfall, (*c*) average temperature—for each month of the year. Examine and compare the



graphs. Against each of the following statements write one of the letters A, B or C. These letters are to indicate that (for the particular town):

A—the graph shows that the statement is true;
B—you consider that the graph gives insufficient evidence;
C—the graph shows that the statement is false.

..... (i) The health of young people is less affected by the weather than that of old people.

..... (ii) The colder the weather, the healthier is the climate.

..... (iii) There are more deaths in February than in December.

..... (iv) July is the healthiest month.

..... (v) Many people die of malaria.

..... (vi) Most rain falls during the hottest months.

..... (vii) Wet weather is bad for the health of the people.

..... (viii) It most often rains between 6.0 and 8.0 p.m.

..... (ix) The weather gradually gets colder from July to December.

..... (x) Women live longer than men.

..... (xi) The more it rains, the cooler it is.

..... (xii) If strangers like cool, dry weather, it is better for them to visit the town in August rather than April.

2. Carbon dioxide is evolved when a dilute mineral acid is added to washing soda. A boy poured some liquid on to a few crystals of washing soda and found that they did not 'fizz' (effervesce). On the evidence available, write one of the letters, A, B, C or D, against each of the following statements, according to whether you consider that:

A—it is true;
B—it is possibly true;
C—there is no evidence;
D—it is false.

..... (i) The liquid was water.

..... (ii) The boy failed to heat the mixture.

..... (iii) He did not add enough of the liquid.

..... (iv) The washing soda had already lost its water of crystallization.

..... (v) The liquid was not a dilute mineral acid.

..... (vi) The liquid was alkaline.

..... (vii) There was a colour change.

..... (viii) The gas given off turned lime-water milky.

3. You are given the following facts:

(*a*) All sugars contain carbon, hydrogen and oxygen—the last two elements being in the same proportions as in water.

(*b*) Concentrated sulphuric acid readily absorbs water.

(*c*) Concentrated sulphuric acid was added to ordinary (cane-) sugar in a test-tube and the mixture was warmed. It turned black.

Making use only of the facts given, write one of the letters, A, B, C, D or E, against each of the following. The letters are to mean:

A—the statement is true;
B—the statement is probably true;
C—there is no evidence for the statement;
D—the statement is probably false;
E—the statement is false.

..... (i) The mixture turned black because it was burned.

..... (ii) Because starch is built up from sugars it will therefore turn black when treated with warm, concentrated sulphuric acid.

..... (iii) The black residue contained carbon.

..... (iv) At the end of the reaction all the sugar was decomposed.

..... (v) Hydrogen and oxygen were removed from the sugar in the form of water.

..... (vi) If water and carbon are mixed together, sugar is formed.

..... (vii) Sulphuric acid reacts with sugar because acids are sour and sugars are sweet.

..... (viii) Sugar is composed of carbon, hydrogen and oxygen.

..... (ix) Every sugar turns black when treated with warm, concentrated sulphuric acid.

..... (x) Cold sulphuric acid does not react with sugar.

The correction of short-answer papers—The correction of test papers is an onerous but unavoidable task. Test papers of the short-answer types can often be arranged so as to reduce the time taken in their correction.

(*a*) The question paper can be set out so that the answers are to be written, on the same paper, in a column near the right-hand margin. The teacher writes the correct answers on another paper which becomes the 'key'. The key is then placed upon each pupil's answer paper in turn, so that the answers in the 'key' lie exactly by the side of the pupil's answers. It is then easy to check the second by the first. Some questions from a paper of this type are given below: Instruction to pupils, 'Write your answers in the margin provided'.

(A) 1. Name the active constituent of air.	....
2. What name is given to compounds of this gas with other elements?	....
etc.	

(B) Place a 'T' or an 'F' in the space provided in the margin according to whether the following statements are true or false:

1. Moist air is heavier than dry air. ( )
2. Carbon dioxide supports combustion. ( )

etc.

(C) Write in the margin the word which does not seem to belong to the same group as the others.

1. Iron, copper, carbon, tin. ....
2. Salt, air, copper oxide, ammonia gas. ....

etc.

(*b*) When a large number of pupils take the examination, but it is inconvenient to use the above system, another method of quick and accurate marking is available. A sample paper is as follows:—
Instruction to pupils: 'Fill in the blanks in the following statements':

1. If two resistances, each of 3 ohms, are connected in series, their combined resistance is .... ohms. If connected in parallel their combined resistance is .... ohms.

2. D.C. stands for ...., A.C. stands for ....

3. Iron filings are most readily attracted to the .... of a magnet.

4. Attraction is shown by a steel magnet and an unmagnetized steel bar, but if two steel bars show ...., then .... are.......

etc.

A 'key' is prepared as follows. A copy of the question paper is placed on a piece of stiff paper, or cardboard, with carbon paper between them. The spaces where the answers are to be put are outlined on the question paper, thus leaving a trace on the cardboard below, and these traces are then cut out by means of a sharp knife. When this is placed over the answer papers the pupils' answers appear through the spaces and the teacher's eye is not distracted by the typescript. Written on the 'key', above the spaces, are the correct answers. As the pupils' answers appear immediately under the correct answers, checking is easy and rapid.

(2) *Long-answer questions*—Short-answer questions provide a means for exercising and evaluating reasoning powers, and for revising and

testing factual knowledge. There are other skills which a science course should develop. The study of science provides a great opportunity for directing the attention of a pupil to the need for the precise use of words, for the writing of concise and accurate paragraphs, for setting out an argument in a logical manner, and for describing a process with proper attention to the sequence of operations involved. These skills cannot be developed or tested by short-answer tests.

To ask 'Which are better, long or short-answer questions?' is to miss the point. They are two tools devised to serve different purposes. A chisel is not better than a saw: each has its proper function. A man who used either chisel or saw for the same job would forfeit any claim to be a skilled carpenter. Similarly a teacher who uses either long or short-answer questions for the same task, or who restricts his tests to one type only, equally forfeits any claim to being competent. A well-designed examination paper will contain both types of questions. Statements of fact, and exercises in thinking will be dealt with in short-answer questions. Long-answer questions will provide the student with an opportunity to demonstrate, and the teacher to evaluate, other abilities.

In the following pairs of questions the first is of the short-answer type, the second is of the long-answer type. It is profitable to compare them.

(*a*) (i) Fill in the blank spaces:—
Insects have .... legs. Their bodies are divided into three parts named ...., ..., and .... respectively.

(ii) Describe how an ant colony is organized and how its various 'chambers' are arranged. Describe the various activities carried out by different groups in the colony and state how each group is adapted to its own task.

(*b*) (i) Fill in the blank spaces:—
Carbon dioxide is .... in water, ... to litmus, ... than air, ... combustion, and turns .... milky.

(ii) Describe the part carbon dioxide plays in the respiration and growth of plants.

(*c*) (i) Write, in the spaces provided, the chemical formulae of the following gases: ammonia (....), oxygen (....), carbon dioxide (....), nitrogen (....), hydrogen (....).

(ii) How did the discoveries of Avogadro, and the arguments of

Gay Lussac, lead to the belief that hydrogen in the free state is composed of molecules, each containing two atoms?

(*d*) (i) Cross out words and phrases from each group of the following, so that a correct statement remains:

Light waves are shorter than $\left\{\begin{matrix}\text{sound waves}\\ \\ \text{wireless waves}\end{matrix}\right\}$. They $\left\{\begin{matrix}\text{always}\\ \text{sometimes}\\ \text{never}\end{matrix}\right\}$ obey the same laws of reflection.

(ii) Explain how internal reflection takes place, and how good use of the phenomenon is made by means of a prism in a prismatic compass.

(3) *Tests based on diagrams*—Remarks on the drawing of diagrams have already been made (Chapter VII, page 122). Pupils' diagrams provide revealing commentaries on powers of observation and the extent to which lessons have been understood. The more limited the facilities for practical work, the more emphasis should be given to diagrams. Pupils may be required to draw diagrams themselves, or to correct diagrams which are provided.

The points to look for in assessing the merits of a diagram are:

(i) Does it represent an apparatus which will serve the purpose required?
(ii) Are the parts shown in reasonable proportion?
(iii) Is it neatly drawn?
(iv) Is it neatly and accurately labelled?

For the last two a certain minimum standard should be required before any credit whatever is given for a diagram.

The teacher should have in his mind some allotment of maximum marks under each of the four headings. (The first heading, as in many biological drawings, may not always be appropriate to the exercise.) A suggested allotment of marks for the above requirements, out of a maximum of 10, is:—(i) 4; (ii) 2; (iii) 2; (iv) 2. The marking of diagrams is likely to be inconsistent unless some such standard is applied.

The drawing of an apparatus showing the preparation of carbon dioxide and its passage into lime-water may serve as an example. (1) Unless the teacher specially asks for one or the other, it is not a matter of consequence whether the vessel shown is a test-tube, a round-bottomed flask, a flat-bottomed flask, a conical flask or a Woulfe bottle; nor whether the lime-water is shown in a test-tube or some other small container. (2) Errors in proportion include (*a*) tubes too wide, or (*b*) too long; (*c*) sides of conical flasks with exaggerated slope; (*d*) bottle necks too short or too long. A question to be asked of a pupil who provides a diagram showing apparatus out of proportion is 'Would you expect to buy an apparatus that looks like this?' The following are examples of twenty-minute exercises:—

1. Draw and label diagrams of the following:—

   (*a*) a water suction pump;
   (*b*) a water manometer;
   (*c*) a water wheel (any type).

2. Draw and label diagrams of the following:—

   (*a*) 3 stages in the germination of a bean;
   (*b*) 3 stages in the germination of maize;
   (*c*) how a mangrove tree reproduces itself.

3. Draw and label diagrams of the following:—

   (*a*) an inclined plane, with movable load, scale-pan and weights;
   (*b*) a wheel and axle with weights;
   (*c*) a differential pulley system.

Examples requiring the correction, if necessary, of diagrams provided by the teacher are shown later (see 'Ability to analyse', page 156).

(4) *Numerical tests*—Tests can be designed to give a quick review of physical facts, in so far as these provide data for simple calculations. In such tests the arithmetic required should be reduced to a minimum, for it is the knowledge of, and ability to apply, physical laws which are the real subjects of investigation. A sample list of ten such questions follows. They are appropriate for a General Science class in its third year.

1. Six volts applied to an electric circuit gave a current of 2 amps. What was the resistance in the circuit?

2. Express 55° C. in ° F.

3. If a certain current deposits 1 g. of silver from a solution in

15 minutes, how much silver would be deposited by a current twice as great in one hour?

4. If a sample of gas occupies 120 c.c at 27° C., how many c.c. will it occupy at 127° C. and the same pressure?

5. On a day when the atmospheric pressure is 15 lb. per sq. in. a fully extended bicycle-pump piston is pushed half-way down the barrel before air enters the tyre. What is the pressure of air in the tyre?

6. If a weight of 2 ounces extends a 10-inch spring by 0·8 inch, how long will the spring be when a weight of 1 lb. is hung from the end?

7. A light (A), placed 10 feet from a wall, illumines it as effectively as another light (B), placed 5 feet from the wall. How many times brighter is A than B?

8. A strip of brass, 20 cm. long, is fastened rigidly at one end. It is then plucked and gives out a certain note. How long must the strip be to give a note two octaves higher?

9. Where must a weight of 60 g. be put, on a weightless lever, in order to balance another weight of 40 g. placed 10 cm. from the fulcrum?

10. A pendulum (A) makes a complete vibration in 0·5 sec. A pendulum (B) makes a complete vibration in 2·0 secs. How many times longer is B than A?

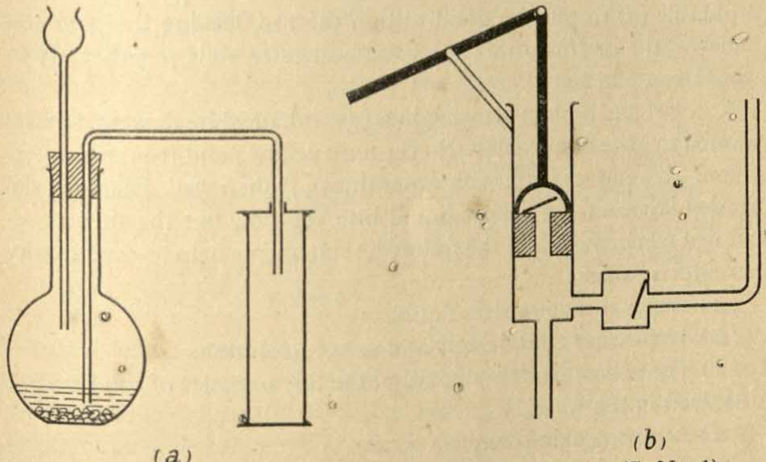


FIGURE 19.—Diagrams for correction (page 156, section (5), No. 1)
(*a*) An apparatus for the preparation of carbon dioxide
(*b*) A force pump

(5) *Testing ability to analyse*.—The following is a selection of examples designed to test analytical reasoning:—

1. Correct the following diagrams: (see Figure 19, page 155).

2. Two electric lamps and two switches are connected up as follows: (see Figure 20).

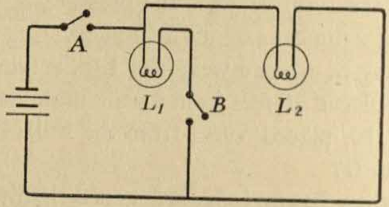


FIGURE 20.—Lamps in circuit: a switch-closing problem

What lamp or lamps light up if—

(*a*) The switch A is closed?

(*b*) The switch B is closed?

(*c*) Both switches are closed at the same time?

3. The soil around your home is poor and you obtain some good soil from elsewhere to make a small garden 6 feet square. Is it more profitable (*a*) to put the good soil on the top, leaving the poor soil underneath; or (*b*) to mix the good and poor soils together? How would you find out?

4. A girl had a plant growing in a pot. It had white flowers, but she wanted to have them yellow. So she took yellow paint from her water-colour box and mixed it with water drawn from a well. Each day she poured some of the yellow liquid into the pot, but the flowers remained white. Which of the following statements help to explain why her efforts failed?

(*a*) Water is a colourless liquid.

(*b*) Well-water contains air and salts in solution.

(*c*) The yellow paint is a mixture: the tiny particles of solid are not dissolved in the water.

(*d*) All living things require water.

(*e*) The roots of plants take in only dissolved substances.

(*f*) A plant makes its own colours from substances in the air and the soil.

(*g*) The roots of plants vary greatly.

(*h*) In hot countries plants usually require a lot of water.

5. As the affinity for oxygen increases, metals more readily displace hydrogen from water. The series of metals, A, B, C, D, is in order of decreasing ability to displace hydrogen from water. Which metal has the greatest affinity for oxygen?

6. Two liquids A and B are put in basins in the sun. The basins are of the same size and shape, and there is the same amount of liquid in each. B dries up later than A. Which has the higher boiling point?

7. An observer notices that he is standing in a straight line with two distant trees. As he walks off (in a direction roughly at right-angles to this line), he sees that one tree (A) appears to move forward a little with him, whereas the other (B) seems to fall behind at once. Which tree is the nearer to him?

8. There are four samples of soil labelled A, B, C and D. A comes from a region of sufficient rainfall and is known to be good soil. B comes from a region of sufficient rainfall but is known to be poor soil. C and D come from very dry regions. Each of the four is shaken up with water and the mixture allowed to settle. Samples A and C take longer to settle than the other two. Which soil comes from the region most likely to benefit by irrigation?

9. A number of cardboard cases of thermometers are coloured either red, blue, yellow or green. The thermometers are able to measure temperatures within the following ranges:—

– 10° C. to 110° C. (red)
– 20° F. to 50° F. (green)
0° F. to 50° F. (green)
12° F. to 250° F. (blue)
50° C. to 120° C. (yellow)
0° F. to 260° F. (blue)
– 10° F. to 200° F. (green)
30° C. to 300° C. (yellow)
0° F. to 220° F. (blue)

During a lesson some pupils are required to check (*a*) the boiling point of water; others to check (*b*) the freezing point of water; and others again to check (*c*) both the boiling and freezing points of water. In the table below put crosses in the spaces against each colour to show whether the thermometers in the cases of that colour are suitable for checking (*a*) and/or (*b*) and/or (*c*). (One line has been filled in.)

Colour	(a) *B. Pt.*	(b) *F. Pt.*	(c) *Both*
Red	×	×	×
Blue			
Yellow			
Green			

10. The reaction of certain metals is described as follows:—

Magnesium—with steam forms hydrogen and magnesium oxide.
Sodium —reacts fiercely with cold water to give hydrogen and a solution of caustic soda.
Copper —has no reaction with water or steam.
Calcium —reacts slowly with cold water to give hydrogen and lime-water.

Arrange these four facts in logical order.

11. In one kind of flower the ripe pollen and the sticky stigma may appear at the same time, or the pollen may ripen before the stigma becomes sticky, or the stigma may perish before the pollen ripens. Which condition or conditions make self-pollination difficult?

12. A manufacturer may advertise his goods by claiming:—

(*a*) We have three thousand satisfied customers.
(*b*) In the supply of these goods we have no competitors.
(*c*) Two hundred doctors recommend our products.
(*d*) We guarantee to return your money if you are not satisfied with our goods.

To which claim would you pay most attention and why?

(6) *Tests for ability to propose hypotheses* [1]—The following types of question can be devised:—

1. Certain flowering plants do not 'set' seeds when their flowers are covered with thin cotton gauze. The same flowers, left untouched, do 'set' seeds. What possible reasons can you give for the differences in behaviour?

2. Make a list (*a*) of living creatures that run away when frightened

---

[1] Tests of the short-answer, logical selection type, provide a means of estimating this ability. (*Note:* If two hypotheses can explain a fact, the scientist assumes that the simpler is more likely to be correct.)

and a list (*b*) of living creatures that keep still when frightened. Against each creature put adjectives describing it, for example 'big', 'small', 'fast', 'slow', 'striped', 'spotted', its colour, and so on. Then look through each list to find any particular characteristic common to all the creatures named in it, giving the clue as to why they behave as they do. What are these common characteristics?

3. The sun at noon is farther to the north at certain seasons of the year than at others. This is because the earth's axis is not at right-angles to the plane of its orbit. The moon at its highest in the heavens is sometimes even farther north than the sun. Suggest a reason for this.

4. For what reasons might a teacher of science decide to keep a substance in a bottle locked away in a cupboard?

(7) *Testing ability to interpret evidence*—The following is a selection of suitable examples:—

1. Plants and trees are provided with tubes (vascular bundles) through which fluids flow up and down the plant from soil to leaves and from leaves to roots. If you make a cut around the outside of a palm-tree and remove a layer of material, the plant will probably survive, but if you do the same thing with other trees ('ring' them) they will die. What does this show about the position of these 'tubes' in palms and other trees?

2. If you went to a certain country and found there many plants with thick shiny leaves, what sort of climate would you expect the country to have?

3. If you hold a large open-ended tube vertically in a vessel of water, so that it is partly in and partly out of the water, then the water level inside and outside the tube is the same. People say 'Water finds its own level'. But if the tube is a narrow one, the levels inside and outside the tube are not the same. Does this mean that 'water does *not* find its own level'?

4. A certain white salt has glassy crystals which often show white, powdery patches. When heated it releases much water of crystallization. When treated with dilute acid it fizzes and gives off carbon dioxide. The salt seems plentiful and cheap. What is it likely to be?

5. A dark purple (almost black) solid, in small flakes, turns to a deep purple when heated. What is it?

6. A boy cut his knee and put tincture of iodine on the cut. Later he saw that his white trousers showed a blue patch where the iodine had touched it. Why did this colour appear?

7. A careless cook, at work in his kitchen, spilled some vinegar into an open tin containing a white powder. The solid fizzed up. What were the probable contents of the tin? For what purpose might the powder have been intended?

(8) *Tests for ability to generalize and draw conclusions*—Questions of the following type help to provide the required information:—

1. On the advertisement attached to a camera film the following times for exposure are placed against corresponding sizes of apertures:—

Lens aperture . . .	f/16	f/11	f/8	f/5.6	f/4
Exposure time in secs. .	$\frac{1}{5}$	$\frac{1}{10}$	$\frac{1}{25}$	$\frac{1}{50}$	$\frac{1}{100}$

(*a*) Which is the larger aperture, f/16 or f/4?

(*b*) How many times bigger or smaller in area is f/4 than f/8?

2. The following facts were noted during one week by the pupils of a certain school:—

Maximum day temperature	*Rainfall*
88° F.	nil
87° F.	nil
91° F.	1·02 in.
89° F.	trace
89° F.	nil
93° F.	1·85 in.

What general conclusion is suggested by these figures?

3. If a person has nothing but carbon dioxide to breathe he dies of suffocation. To restore normal breathing to a person suffering from electric shock he may be made to breathe air which contains a little extra carbon dioxide. Is carbon dioxide poisonous? Give the reason for your answer.

4. The following are some properties of four metals:—

(A)—Heavy, conducts heat and electricity, forms an oxide which is insoluble in water, reacts very slowly with water.

(B)—Heavy, very good conductor of electricity, forms oxides which are insoluble in water, has no reaction with water.

(C)—Light, forms an oxide which is very soluble in water, has a violent reaction with cold water.

(D)—Light, conducts electricity, forms an oxide which is fairly soluble in water, reacts moderately with cold water.

Examine the descriptions and answer the following questions:—

(*a*) Are coins likely to conduct electricity?

(*b*) The oxide of a certain metal is insoluble in water. Is the metal likely to react vigorously with water?

(*c*) If you want a good conductor of electricity will you choose a heavy or a light metal?

(*d*) A metal reacts violently with water. What other properties is it likely to possess?

(*e*) Are oxides of lead likely to dissolve in water?

5. In what way does a screw jack resemble an inclined plane?

6. Why are whales classed as mammals? What characteristics, usually associated with mammals, do they lack?

(9) *Tests for ability to apply scientific principles*—The following are typical examples:—

1. A table gives the following data:—

When the pressure is 780 mm. of mercury the B. Pt. of water is 100·7° C.
,, ,, ,, ,, 770 mm. ,, ,, ,, ,, ,, ,, ,, 100·4° C.
,, ,, ,, ,, 760 mm. ,, ,, ,, ,, ,, ,, ,, 100·0° C.

What is the boiling point of water likely to be when the pressure is 765 mm. of mercury?

2. When a stone is swung round on the end of a piece of string, it tends to fly outwards from the hand that holds the string. When a train goes round a curved track, which rail gets the most wear?

3. A row of four spring balances lies along a bench, the top ring of one fastened to the hook of the next, and so on. The first and last are then pulled apart so that they all begin to stretch. When the first one shows a pull of 1 lb., what are the 'weights' registered by the second, third and fourth balances?

4. When is a leaf likely to contain most starch: in early morning or late afternoon?

5. A long plank of wood is carried on the heads of two men. Is it better for each to be at his own end of the plank, or for each to be,

say, 2 feet from his respective end, or to be, say, 4 feet from his respective end?

6. Three hills, A, B and C, are such that A is higher than B, and B is higher than C. The pipe leading water from the top of A to the top of C passes over the top of B. Would the pressure at the top of C be any different if the hill B were removed?

7. Of two bottles the larger is twice as big in every direction as the smaller one. How many small bottles of liquid will it take to fill the large bottle?

8. A person who wanted to cool a cup of hot liquid tried various ways:—

(*a*) He blew over it.

(*b*) He put a spoon in it so that the handle stuck out of the liquid.

(*c*) He rubbed the outside of the cup quickly.

(*d*) He tied a piece of cloth around it.

(*e*) He poured it out into the saucer.

(*f*) He kept pouring the liquid from one cup to another.

(*g*) He put it on a wooden stand.

Which method was most likely to be successful?

9. [To follow a lesson on resonance] Engraved on a brass plate fixed in the engine room of a large ship is the inscription 'Engines not to be run at speeds between 52 and 63 revolutions per minute.' What might be the reason for this warning?

10. Five different liquids have the following densities: (A) 1·3; (B) 0·7; (C) 1·12; (D) 1·05; (E) 0·82 g./c.c. respectively. An insoluble object has a density of 1·08 g./c.c. In which liquids will it sink?

11. When an object is weighed suspended in water it appears to weigh less than when it is freely suspended in air. What would you prefer to call the difference in weight: 'loss in weight' or 'upward thrust'? Why?

12. If you could first weigh an object suspended in air, and then weigh it suspended in a vacuum, would you expect to find any difference in weight? Why?

13. In order to extinguish a big blaze, a boy blew on it as he would do to extinguish a lighted match. Was this a useful method? Why?

14. Is there any common knowledge supplying evidence to suggest that hot air has a different refractive index from cold air?

15. When attempting to make a fire of sticks, some people will not

allow sunlight to fall on the sticks. They say that sunlight puts out a fire. Is there any truth in this? Why?

16. Before putting a cutting into the ground in the hope that it may take root, some gardeners cut off all the leaves. Does this serve any useful purpose?

17. Suppose someone gives you a glass of water which he says is good to drink. What tests, other than those requiring laboratory apparatus and chemicals, could you apply to find out whether his statement is likely to be true?

18. A person who often buys meat at a market always wraps it in a wet cloth before he brings it home. Why is this a good habit?

19. Which is the best of local methods of storing grain, and why?

20. There are places where the feathers are plucked out of live fowls in order, it is said, to make them lay more eggs. Is this practice likely to be successful?

21. Is an iron roof better or worse than an asbestos one as a protection against lightning? Why?

(10) *Tests requiring ability to plan experiments*—The following are examples:—

1. How could you find out which of a number of people has the most acute sense of hearing?

2. How could you find out which local tree provides the best firewood?

3. Suggest how you could discover which keeps fresh for a longer time, boiled local milk or tinned milk diluted with distilled water.

4. What records would you need to keep, and how would you arrange the inquiry, if you wished to find out what difference it made to the laying ability of local hens to give them (*a*) a small amount of grain daily, (*b*) broken sea-shells occasionally?

5. Describe how you would find out which of two kinds of seeds contained the most moisture.

6. How would you find out which trees provide the best timber for posts for fences?

7. How could you find out which of the various oils available (including car engine oil) is the best lubricant to use between wooden surfaces?

8. Devise an experiment to show which of a number of liquids pours most easily.

9. How could you find out whether it is better to water pot plants in the morning or in the evening?

10. Suppose you are given two wires, made of different metals, one twice as thick as the other. How could you find out which metal conducts an electric current the more readily?

11. Two tubes have the same length (about 6 inches), but one has an area of cross-section twice that of the other. What method do you suggest for finding out how much faster water flows through one than the other? How would you find out whether a change of temperature, or an alteration in the 'head' of water, makes any difference?

12. How would you find out whether all drops have the same size?

13. Do the leaves of plants become green when only coloured light falls upon them? How would you arrange an experiment to confirm your answer?

14. Suppose a friend says that his thermometer does not register the correct temperature. If you have a thermometer of known accuracy, how can you prepare for him a chart giving the correct temperatures corresponding to readings of his thermometer?

15. How could you compare the brightness of a 3-cell electric torch with that of one containing 2 cells?

16. You have a balance made to weigh up to 200 g. only. You are given a packet of large sheets of paper—about 500, all of the same sort and size. How will you obtain an accurate value for the weight of a single sheet?

A specimen examination paper

The following is an examination paper, consisting of different types of question, which might well follow a project on 'magnetism':—

1. Fill in the blanks in the following:—

(*a*) A freely suspended magnet points to the .... poles. The earth's north pole is now situated in .... The angle between true north and .... north is called the .... In this school the angle is ....° ....′

(*b*) Permanent magnets are made of ....

(*c*) The rule that describes the reaction between magnetic poles is: .... poles attract, ... poles ....

(*d*) If one end of an iron nail is held against the north-seeking end of a magnet, the other end of the nail is ....-seeking.

2. Cross out words or phrases from each group so that a correct statement remains:—

(*a*) A magnet $\left\{\begin{array}{l}\text{will}\\ \text{will not}\end{array}\right\}$ attract an iron nail if a sheet of $\left\{\begin{array}{l}\text{paper}\\ \text{copper}\\ \text{iron}\end{array}\right\}$ is placed between them.

(*b*) If a magnet rests on a cork floating freely in water, at a place in the northern hemisphere, the magnet tends to $\left\{\begin{array}{l}\text{move northwards}\\ \text{move southwards}\\ \text{stay where it is}\end{array}\right\}$ because the north magnetic pole $\left\{\begin{array}{l}\text{attracts}\\ \text{repels}\end{array}\right\}$ the south pole of the magnet $\left\{\begin{array}{l}\text{as much as}\\ \text{more than}\\ \text{less than}\end{array}\right\}$ it $\left\{\begin{array}{l}\text{attracts}\\ \text{repels}\end{array}\right\}$ the north.

3. Draw and label diagrams of the following:—

(*a*) A pair of bar magnets with their keepers.

(*b*) An arrangement showing how a magnetic compass can be used to compare the strength of two magnets.

(*c*) An arrangement showing how a magnetic compass can be used to detect an electric current.

(*d*) The direction of the lines of magnetic force when two bar magnets are placed near to one another, side by side, with their north ends pointing in the same direction.

4. On the accompanying diagram (see Figure 21) of an electric bell, label the parts, show how the electric wires are connected, and indicate with arrows the route taken by the current.

5. (*a*) Describe two different methods of turning a steel knitting needle into a magnet.

(*b*) How could the needle be made to lose its magnetism?

(*c*) Describe a theory that might explain why the methods of magnetizing and de-magnetizing are successful.

6. Given a reel of D.C.C.[1] copper wire, a dry battery and some iron

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[1] Double cotton-covered.

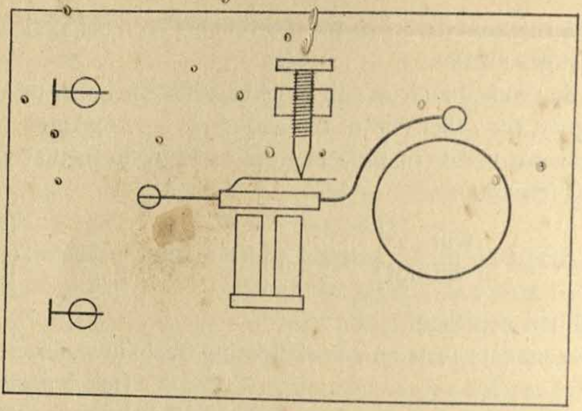

FIGURE 21.—A diagram for completion: to insert the wiring of an electric bell (see example 4 on page 165)

nails, describe how you could send messages in morse from one classroom to another. What odds and ends would you suggest might be obtained to improve the efficiency of the apparatus, and how would you arrange them?

7. Imagine a world where there is no such thing as magnetism. How would it differ from ours?

Some 'practical' tests

Any of the usual laboratory experiments may occasionally be used as tests, but it is often useful to examine practical work by other methods.

(1) *Tests of skill in measuring and reading scales and verniers*—From time to time a test such as the following provides a necessary and welcome change. A collection of various devices is arranged around the laboratory and numbered in sequence, there being as many pieces of apparatus as there are members of the class (in this example 24 pupils). Each pupil provides himself with a sheet or strip of exercise paper, the lines being numbered from 1 to 24. Each pupil is given a different number, and begins with the experiment of the same number. Each takes his reading or makes his experiment and records the result against that same number on his paper. At a word of command

from the teacher, each pupil moves to the apparatus with the next (higher) number, the pupil performing experiment 24 moving to experiment number 1. It is important that all pupils should move on to their next experiments at the same time, otherwise unnecessary confusion results. A suggested collection of experiments is as follows:—

Expt. 1. Find the length of 15 centimetres in inches. (Two rulers are provided.)
Expt. 2. Find the circumference of the given glass tube by winding a piece of cotton thread 30 times around it and measuring the length of the thread used.
Expt. 3. Read the water level in the burette provided.
Expt. 4. Read the water level in the graduated glass cylinder (200 ml.) provided.
Expt. 5. Read the model vernier (graduated in inches). The vernier must *not* be touched.
Expt. 6. Read the centigrade thermometer resting on the bench.
Expt. 7. Record the weight of the object suspended from the (100 g.) spring balance.
Expt. 8. Use the hydrometer (1·000–1·200) to find the density of the liquid in the glass cylinder.
Expt. 9. Estimate the thickness of the given wire using the micrometer screw gauge.
Expt. 10. Measure the length of the curved line, drawn on the sheet of paper fastened to the bench, by rolling a coin along it.
Expt. 11. Measure the internal and external diameters of the large glass tube provided, using ordinary (or vernier) callipers.
Expt. 12. Use the magnetic compass to determine the direction of the line drawn on the bench.
Expt. 13. As No. 1. Find the length of 9·55 inches in centimetres.
Expt. 14. As No. 2. (A tube of different diameter is provided.)
Expt. 15. As No. 3. (A burette containing a different quantity of water is provided.)
Expt. 16. As No. 4. (A 10-ml. cylinder is provided.)
Expt. 17. As No. 5. (A different vernier, graduated in centimetres, is provided.)
Expt. 18. Read the Fahrenheit thermometer resting on the bench.

Expt. 19. Record the weight of the object suspended from the spring balance (graduated in pounds and ounces).
Expt. 20. As No. 8. (A liquid suited to a hydrometer graduated from 0·800–1·000 is provided.)
Expt. 21. As No. 9. (A wire of a different thickness, or a piece of thin sheet metal, is provided.)
Expt. 22. As No. 10. (A line of different length is given.)
Expt. 23. As No. 11. (A tube of different diameter is provided.)
Expt. 24. As No. 12. (The line is drawn in a different direction.)

The answer required in each of the above instances is a number, but pupils must understand that it is essential to give also the unit of measurement. The class should be clearly instructed that no credit will be given where the unit of measurement is not stated. At least 12 such experiments can be performed by each pupil during a double lesson-period of 80 minutes. The teacher should have a sheet of paper, identical with that used by the pupils, showing the limits within which answers should lie. This 'key' might read, for example:—

Expt. 1. 5·85 to 5·95 inches
Expt. 2. 1·38 to 1·48 centimetres
Expt. 3. 22·20 to 22·30 ml.
Expt. 4. 123·3 to 123·7 ml., etc.

The teacher can then lay his 'key' side by side with each of the pupils' lists in turn, so that marking of answers can be done in the minimum time. He can then help individuals, or groups, who have made mistakes.

(2) *Other exercises and tests of manipulative skill*—Manipulative skill is brought into play every time a pupil carries out an experiment. Within any course there are experiments of widely varying degrees of difficulty. Dissections carried out in biology classes are usually far greater tests of manipulative skill than the handling of most pieces of physical or chemical apparatus. Consequently greater credit can be given for a neat dissection than for an estimation of density. Titrations call for more skill and judgement than, for example, the preparation of oxygen.

Tests of immediate value can be set deliberately. For example:—

1. Take an ordinary cork and soften it by pressing or rolling. Bore a hole (of given diameter) through the centre.

2. Take a piece of glass tubing: cut it to suitable length, bend it to provide a duplicate of the sample bent tube provided, and smooth off the sharp ends in a flame.

3. Blow a small bulb on the end of a piece of glass tubing.

4. Seal off, neatly, a piece of glass tubing to provide a specimen tube (or an ignition tube, or a tube suitable for finding the melting point of small quantities of a substance of low melting point).

5. Take a piece of glass tubing and draw it out to form a capillary tube.

6. Set up an apparatus to demonstrate the expansion of a metal rod. The iron rod of a retort stand, some blocks of wood, a needle and a straw (or the spine of a palm frond), are provided.

7. Arrange a set of four single pulleys to give a pulley system with a mechanical advantage of 8.

8. Given a ruler, a triangular file and a known weight (say 20 grams), find the weight of any symmetrical object (say from 15 to 50 grams).

9. Fold a filter paper so that it opens like a fan and can be used in a funnel for rapid filtration.

10. Measure out 80 grams of some dry powder such as calcium carbonate, and place it on a sheet of paper. By successive division into halves, using a spatula or a ruler edge only, prepare 16 heaps of approximately 5 grams each. Place each heap on a filter paper and find, by weighing, which is the heaviest and which the lightest heap, and also the difference in weight. (This method of weighing out small quantities of powders is used by pharmacists.)

Certain tests have entertainment as well as instructional value. The following suggestions will help teachers:—

1. Parts from constructional toy sets are supplied with the necessary instructions for making a simple model. Pupils, in turn, attempt the construction of the model and are timed to see how long they take to complete it.

2. The following can be provided: lengths of double-cotton-covered copper wire, a plug key or tapping key, a variable resistance, an accumulator, and an ammeter. Pupils are timed to find out how long they take to wire up the parts to produce a steady current of, say, half an ampere, in the circuit.

3. An electric lamp holder is provided. Pupils are timed to find out how long they need to take it completely to bits and reassemble it.

4. A burette is partly filled with ink. A pupil is required to make a pattern of single drops, say ten drops to make three sides of a square, on a white tile.

5. Pupils are asked to pour one drop of liquid from a bottle into a test-tube. (With the aid of the stopper, the edges of the neck of the bottle should first be wetted by the liquid.)

6. A bar magnet is to be suspended from cotton loops (see Figure 73, page 260).

7. A smooth brass sphere, or a table-tennis ball, must be hung up using cotton thread only.

8. A pin is to be held in the fingers and placed gently on the surface of a bowl of water so that it remains floating.

9. Pupils are asked to pour a liquid into a burette so that, without further adjustment, the level reads a certain figure (say 25·65 ml.).

10. By means of a piece of glass tubing pupils must lead out unburnt gas from the centre of a smoky bunsen flame. The gas is then to be lit at the upper end of the tube. From this second flame, by means of another and smaller tube, unburnt gas is again to be led off and set alight. An attempt should be made to repeat the experiment through one more stage using a very short and narrow tube.

(3) *Tests for observation and memory*—The following are simple examples:—

1. A suitable apparatus is set up, and covered with a large cloth. The cloth is removed and pupils are given one minute in which to look at it. The apparatus is then covered over again and they are given fifteen minutes in which to make an accurate drawing of the apparatus from memory.

2. Thirty items of laboratory equipment, ranging from a clip to a bottle of stain, are placed on a tray and covered with a cloth. The cloth is removed and the objects are exposed to view for two minutes. At the end of that time the cloth is replaced, and the pupils are required to write down the names of as many objects as they can remember having seen on the tray.

3. Each pupil is given a flowering plant (or part of the plant with flower or fruit), and is allowed two minutes in which to examine it.

At the end of that time the specimen is put out of sight, and the pupil is required to write any ten facts about it. (It saves time in checking the answers if the facts are listed in a definite order, for example: family type, the flower and its structure, the leaves and their structure, the fruit, etc.)

Specimen questions on local lore

The enthusiastic teacher can compile an almost inexhaustible list of 'scientific' questions concerning local materials, customs and beliefs. In fact man's ignorance is so great that there is endless scope for observation and research at every level. Questions such as the following often inspire pupils to find things out for themselves:—

1. What kinds of wood, used for making furniture in your neighbourhood, are not attacked by white ants (termites)?
2. Where is your nearest supply of good drinking water?
3. How far from your school is the nearest field or farm where plants of a 'pea' variety are grown for food?
4. Where, near school, can you hear an echo?
5. In which direction (from here) do you look 'due south'?
6. Is the sun at noon (today) to the north or the south?
7. How can the pitch of a note given out by a drum be raised?
8. Of what material are the bellows used by local craftsmen made? How do the bellows work?
9. From what local plant can you get yellow dye?
10. At what time of the year do you see a certain (named) migrant bird?
11. At what time of the year do the flowers of a certain (named) plant appear?
12. When do you expect to see Orion overhead in the early evening?
13. At about what time does the new moon set?
14. At what time of the day is the tide highest on your coast?
15. From where does your local
    (*a*) blacksmith get his iron?
    (*b*) brassworker get his brass?
    (*c*) builder get his lime?
16. With what are your cushions and pillows stuffed, and where does the material come from?

17. With what do local firewood cutters tie up their bundles?

18. Where can you see charcoal being made, and how is the process carried out?

19. During what month would you start to raise seedlings of a certain (named) plant?

20. How far must you go to see a water lily (lotus) growing?

21. What local bird lays its eggs upon the ground?

22. What is the length of the longest lizard or monitor in your neighbourhood?

23. List the names of local poisonous snakes and give a brief description of each.

24. Imitate the calls of (named) birds.

25. What weather can you expect when the school sports are held in November (or other named month)?

26. What is the nearest source of cooking salt?

27. What material is used for making local roads, and where is it obtained?

28. What kinds of timber are used in building your school?

29. What local measures are in use? Give their values in terms of grams and cubic centimetres.

30. How is soap made locally?

31. How are the latrines for village schools constructed?

32. What is used locally for making bread 'rise'?

The use of 'quiz' cards

Mention has been made (page 134) of the use of 'quiz' cards. The specimens given in Figure 22 and Appendix D.II, page 304, contain questions covering the whole field of General Science. Similar selections may, of course, be made to cover a more restricted field.

A rather different type of 'quiz' card can be made by mounting various seeds, leaves, etc., on cardboard. The items are numbered and the pupil is asked to write on a piece of paper the names of the plants from which they come. The selected seeds and leaves should be from very common plants, including cultivated plants and shrubs grown in the school compound, as well as those produced by crops of economic value, like sweet potatoes, cassava, cow pea, etc. Seeds may be put in small cellophane bags, and sewn to the card, or fastened on with transparent adhesive tape. Examples of the commonest edible seeds, maize or other cereal, local beans, ground nuts, rice, or whatever is appropriate to the neighbourhood, should be included.

Another variation of the same idea is to prepare one or two racks with numbered test-tubes, each containing a different chemical. The pupil is asked to supply the name appropriate to the number. A row of test-tubes might contain the following: copper sulphate, iron sulphate, crystals of iodine, potassium permanganate, mercuric oxide, sulphur, granulated zinc, granulated copper, naphthalene marbles, magnesium ribbon. An alternative selection may consist of the common elements in the form in which they are usually obtained for laboratory work.

'QUIZ' CARD I	**Answers to 'Quiz' I**
1. How far away is the sun?	92,000,000 miles
2. Name an Italian scientist famous for his connexion with the invention of the telescope.	Galileo
3. These are the jumbled letters of the name of a famous chemist: T, A, L, O, N, D. What is his name?	Dalton
4. How does a whale resemble a rabbit?	Both are mammals
5. What symbol is used by electricians to indicate a transformer?	(See Figure 16, page 125)
6. Who discovered sodium?	Sir Humphrey Davy
7. What is the chemical formula for common salt?	$NaCl$
8. Who wrote a book called *The Origin of Species*?	Charles Darwin
9. To what family does the sunflower belong?	Compositae
10. Whose name is associated with a bottle which has more than one neck?	Woulffe

FIGURE 22.—Example of a science 'quiz' card, with corresponding answer card. (Further specimens are given in Appendix D.II, page 304)

The reliability of marking

If the laws of probability were exactly fulfilled the marks obtained by

OF EDUCATION

members of a class, plotted against the number of individuals obtaining each mark, would produce a symmetrical curve, a curve of distribution. It would assume the shape shown in Figure 23.

Supposing it were required to divide the members of a class into

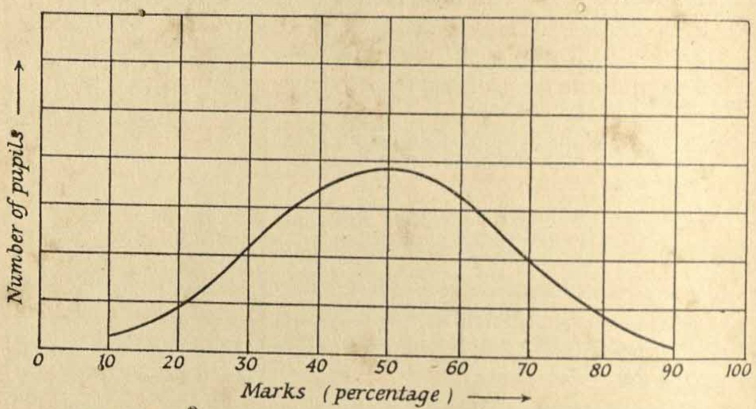

FIGURE 23.—A theoretical distribution curve for a mark list

five grades of ability, then it is theoretically probable that, among 10 students, relative abilities would be: 1 very good, 2 good, 4 average, 2 poor, 1 very poor. By proportion, out of a class of 30, the numbers in each of the five grades are likely to be three times as many, that is: 3 very good, 6 good, 12 average, 6 poor, 3 very poor.

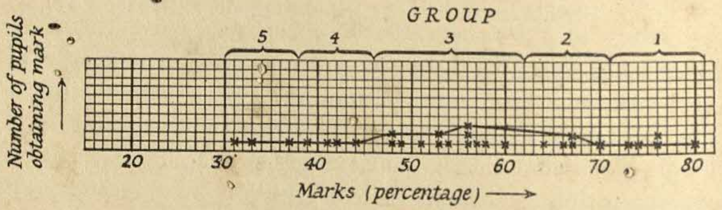

FIGURE 24.—A plot of actual class marks

A teacher is thus provided with a guide as to how to sort out his pupils into categories of varying ability.

It must be remembered, however, that these are mathematical probabilities and the grades are relative.

(*a*) If a class, by reason of very special selection, contains more intelligent children than the average, the numbers in the grades may remain the same, but the appropriate description of each category may need to be changed to: 3 excellent, 6 very good, 12 good, 6 average, 3 poor.

(*b*) If the average ability of the class, for one reason or another, is low, then the appropriate description of each category may be: 3 good, 6 average, 12 poor, 6 very poor, 3 very poor indeed.

(*c*) In actual practice the marks obtained by a class are seldom grouped as exactly as the laws of probability would suggest, because the number of pupils is comparatively small. In these circumstances the teacher must exercise his own judgement. For instance, in a certain class the marks of the pupils, whose names were arranged alphabetically, were 41, 56, 31, 54, 53, 42, 70, 57, 76, 39, 80, 67, 56, 73, 44, 74, 49, 58, 60, 48, 64, 76, 37, 51, 56, 53, 33, 66, 67, 48. Plotted on squared paper the frequency and distribution of the marks are seen to be as shown in Figure 24. Some teachers prefer to plot the frequency of occurrence of each mark against a simple list of numbers, as shown in Figure 25.

It is evident that the class may be arranged so that 5 pupils are in the

83		
82		
81		
80	/	
79		
78		
77		
76	/ /	GROUP 1
75		
74	/	
73	/	
72		
71		
70	/	
69		GROUP 2
68		
67	/ /	
66	/	
65		
64	/	
63		
62		
61		
60	/	
59		
58	/	
57	/	
56	/ / /	
55		GROUP 3
54	/	
53	/ /	
52		
51	/	
50		
49	/	
48	/ /	
47		
46		
45		
44	/	
43		
42	/	GROUP 4
41	/	
40		
39	/	
38		
37	/	
36		
35		GROUP 5
34		
33	/	
32		
31	/	
30		

FIGURE 25.—A method of analysis of a mark list

first group, 5 in the second, and 13 in the third, with 7 remaining for the last two groups. To divide the latter is somewhat arbitrary, but, remembering the theoretical expectation, the teacher is advised to put 5 (or 4) in the fourth group and 2 (or 3) in the fifth group. This divides them into the ratio of approximately 2 : 1 as the theory would require.

Faced with a list of marks, it is not an easy matter for the teacher to determine which marks correspond to the various groups, nor to see whether the gap between two students, next to one another in order, is sufficiently large to justify placing them in different groups. The setting out of marks as shown above takes only a few minutes, and enables a teacher to allot students to their appropriate categories with confidence. When two or more parallel classes are to be considered together, some such aid to reasonably accurate grouping is almost essential.

When the marks of a class have been set out as shown above, various arrangements may become apparent. Nearly all the marks may be low and bunched together, or they may all be high and bunched together, or they may be widely spread. There is no rule about it, but in general, if the marks are all low, the questions have been too hard; if too high, the questions have been too easy. If the marks are reasonably spread out the questions set may be taken as suited to the class.

A pupil and his relatives are not usually able to judge the significance of a percentage mark. A low percentage mark gained in a hard test may be as creditable as a high mark gained in an easy test. It is for this reason that many schools avoid making final pronouncements on a pupil's work in terms of marks. Instead, the pupils are reported as being in one of the five groups already referred to. These are usually indicated by the letters A, B, C, D and E.

CHAPTER IX

Laboratories and their Equipment

The word 'laboratory' is generally applied to a large room in which a class carries out practical work. Other rooms are usually necessary if the science work of a school is to be efficiently organized.

It is convenient to have a '*preparation room*' for the assembly of apparatus to be used in a laboratory or a lecture room. Apparatus not in frequent use, or which has been specially fitted up for an unfinished experiment, can be kept here. A laboratory assistant, or a teacher using a non-teaching period to get ready for his next lesson, can work in a preparation room without occupying space in a laboratory or disturbing a class in session. In the preparation room may be kept tools, glass tubing and glass rod in current use, nails and screws, stirrups and terminals, wire, soldering equipment, a foot-operated blow-pipe for working glass, and the junk which every science teacher with imagination contrives to collect.

A '*store room*' is used as its name implies. Here, permanently under lock and key, are kept the materials which are distributed to the other rooms as they are required. There is need for a store outside the main building in which dangerous chemicals, concentrated acids, etc., can be kept (see Appendix E.II, page 331). A small separate store, for chemicals only, ensures that the general store is free from fumes, thus reducing the rate of corrosion of materials stored in it.

A '*lecture room*' is usually arranged with a demonstration bench in front of a large blackboard. The pupils sit in seats arranged in tiers, so that all may look down upon the teacher's demonstration bench on which the experiments are performed. (A teacher's bench in a laboratory is usually too high for students to see apparatus placed flat upon it.) A 'lecture room' should be provided with window blinds so that the room may be darkened when required. Projection apparatus, with a permanent, or readily available, screen, is normally used in it.

A '*dark room*', permanently darkened, but adequately ventilated, provided with shelves, sink, a dark room light, and an electric supply socket, is useful for de-starching plants, for using special physical instruments such as spectrometers, for carrying out simple experiments on photometry, and for doing any photography which a science club may organize.

Science rooms: arrangement and fittings

Dimensions—The size of a laboratory is adequate if to the floor area occupied by benches, tables, cupboards and shelves is added 25 to 30 sq. ft. for each pupil in the class. If the provision of preparation rooms is inadequate the size of a laboratory should be proportionately increased.

A preparation room should cover about 200 sq. ft.

Store rooms should be not less than 16 feet by 12 feet to allow easy access to shelves and racks. A separate outside store may be smaller.

A lecture room is usually not less than 400 sq. ft. in area and may with advantage be more.

A dark room should be not less than 8 feet wide, so that two persons can work comfortably side by side at the sink.

Arrangement—Where two laboratories are available for teaching physics, chemistry and biology, it is better to use one for physics and biology, reserving the other for chemistry alone. The chemistry laboratory should be placed on the side of the school away from the prevailing wind. Where laboratories have to be accommodated in a two-storey block, the chemistry laboratory is usually on the upper floor, but problems of water and gas supply, drainage, etc., are greatly simplified when it can be situated on the ground floor. One preparation room can readily be shared by two laboratories if it is placed between them and each has direct access to it. Doors should be arranged to permit entrance to a preparation room without passage through a laboratory where a class may be at work. The apparatus needed in a lecture room must be brought to it from elsewhere, and the room should therefore be centrally placed with respect to the laboratories and preparation rooms, if it is to be used often enough to justify its existence. A hatchway leading to a preparation room, opening near the demonstration bench, is sometimes provided.

Behind this hatch, on a wide shelf, can be arranged the materials which may be needed during the lesson and which would occupy too much space if kept on the bench throughout the lesson.

Windows—These should be provided along two opposite sides of a laboratory. One set of windows should face the prevailing wind in order to give plenty of ventilation. A laboratory needs shelves, cupboards, a long bench, a long blackboard, and wall-space for the display of pictures, charts and diagrams. If the wall space, of which there is never too much, is unduly cut up by windows, the arrangement of these fittings becomes one of increasing difficulty. An arrangement which yields light without loss of wall space is attained if the windows on one side are smaller but numerous, and have their sills about 5 feet 6 inches above the floor. All the wall space under such windows is clear. But on the opposite side most, if not all, of the windows should reach down to bench-top level. There should be no windows within several feet of the blackboard. It is better if there are none on the blackboard wall. The side with the larger windows should be towards the north in the northern hemisphere, and towards the south in the southern hemisphere.

Ventilation—Heat is required in carrying out many experiments. If the rooms are not adequately ventilated by a through draught, the conditions in the tropics on a hot day can be almost intolerable. Provided that they are not likely to be struck by driving rain during a storm, permanent louvres may be fitted above the windows, and doors may be similarly ventilated.

Fume chambers and a dark room may be ventilated by ducts leading to one or more exhaust fans, which draw out the stale air and discharge it outside.

Ideally, rooms in the tropics should be surrounded by a verandah on all sides, but in any case a roof overhang of not less than 4 feet is desirable to keep the sun, at its hottest, from striking floors and vertical walls. A verandah is also a protection against heavy storms and driving rain.

Ventilation, like other topics in this chapter, is a matter for discussion during lessons. As usual the teacher should begin with what is close to hand and may therefore take the ventilation of the laboratory as his first example. Pupils may be asked to criticize the system and to suggest possible improvements. (They should realize that in an occupied room the air quickly becomes saturated with water vapour due to breathing and sweating, and that this makes the room feel 'close' or 'stuffy' long before there is any shortage of oxygen and excess of carbon dioxide. They should also understand that expired air is less dense than 'fresh' air, even at the same temperature, because the lighter water vapour more than counterbalances the effect of the heavier carbon dioxide. Hence the warm, moist air is pushed upwards by the cooler, drier air, so that ventilation without a 'draught' is impossible. It is part of an architect's work to design buildings so that the fresh air is diffused without causing uncomfortable draughts. This may lead to a study of 'air-conditioning'.)

Water—Each area has its own problems regarding the provision of water. Methods that have been found suitable for large houses or boarding establishments can be used to provide water for laboratories and preparation rooms. Whether the source of supply is rainwater, well-water, or a supply maintained by a local authority, a storage tank of not less than 1,000 gallons should be provided. There should be a draining plug in the bottom of the tank to facilitate occasional cleaning. There should be a head of water of at least 10 feet. A tap in each room directly connected to a supply at a higher pressure is desirable.

As far as possible, installation of iron pipes should be avoided, especially in any room used for physics.

Space heating—It is unlikely that space heating will be required in hot countries. But if it has to be supplied, then first consideration should be given to providing the most suitable arrangement for the laboratory furnishings. Space heating may be by hot-water radiators, hot-air ducts, or electrical units reflecting heat from the ceilings. Their position in a laboratory is of secondary importance.

Heat supplies—Heating by gas is to be preferred on the grounds of both convenience and economy. Where a local supply of gas is not obtainable a special petrol-gas installation is needed. Power for this may be supplied either by an electric motor, or by the movement under gravity of a system of heavy weights. The latter are hung in a suitable vertical framework, and the weights raised from time to time by a hand crank. Both types are effective, and require little attention. The petrol used is aviation spirit, for the supply of which special arrangements must usually be made. The manufacturers of petrol-gas equipment provide a specification of the petrol needed.

The type of gas burner suitable for use with an ordinary coal-gas supply is not suitable for use with petrol-gas. This should be borne in mind when ordering laboratory equipment. The suppliers must be informed what kind of gas is to be used.

Where mains electricity of 100 volts and upwards is available, certain items of equipment such as water baths, ovens, stills, aquarium aerators and klinostats, are more conveniently run by electricity than gas.

Drainage — Except for the first down-drop from a sink, drains should not be of metal. Waste-pipes from sinks should not be provided with a trap, but should lead directly into open ducts, which in turn empty into open drains, of half-round section, placed just below floor level. The drains should be covered with wooden boards, flush with the floor and easily removable for inspection. The ducts leading from the sink waste-pipe to the drains may be of local damp-resisting wood, lined with lead and coated with bitumen. If the waste-pipe from the sink leads directly into a drain, so much the better. The drains may be made of glazed earthenware, of half-round section, or of cement. A fall of not less than 1 in 50 is desirable.

Waste water from the science rooms should not be run into a septic tank. If it is not disposed of into its own soak-away pit, it should be run only into a waste system carrying plenty of water, so that it is well diluted.

Floors — From the point of view of comfort, acoustics and the possibilities of breaking glassware, a wooden floor is preferable. Its disadvantages, however, usually make it impracticable: (*a*) it is expensive; (*b*) unless thoroughly 'proofed', it is liable to attack by termites, borers, etc.; (*c*) on an upper floor it must be completely waterproofed. A cement floor must therefore be recommended for the tropics, as it is free from these objections, and is more easily swept, washed down and kept in good condition. (Wooden blocks, proof against damp and termites, and laid on a cement base, probably make the best floor, but this ideal is unattainable in most schools.)

Artificial lighting (Electricity)—It is more economical and efficient to light a room, for example, by eight 100-watt electric bulbs rather than with four 200-watt lamps. A person working at a bench finds less areas in shadow. For the sake of economy not more than two lights should be controlled by each switch, so that only those lights actually necessary are used, on a dull day, in the part of the room which is inadequately lit. A separate independent light should be fixed so that the blackboard is well illuminated. Lights should not hang from flexible wire, but should be fixed in batten holders fastened to walls or ceiling.

Acoustics—Difficult hearing conditions do not usually arise when a class is present in a well-furnished laboratory. They may often be remedied, when they do occur, by covering part of the wall-space with compressed fibre board, and by keeping the windows open. Open windows always provide a partial cure for poor acoustics and, in hot countries, will usually be needed for satisfactory ventilation.

Exits—Each room, except the dark room, should have two doors, preferably one at either end, opening outwards, so that in case of fire or other emergency those in the room may leave it without danger or confusion. Grave emergencies may never arise, but they should be guarded against.

Adaptation of existing buildings for science teaching

Good teaching is of primary importance—There are laboratories where the layout is inconvenient and the equipment inadequate, but the standard of teaching is high and the methods used are effective. There are laboratories where the layout is good and the equipment excellent, yet far too little use is made of the available facilities. The teaching is uninspired and the students unresponsive. These facts are not intended to commend the use of unsatisfactory premises or to condone inadequate equipment. They are mentioned to emphasize the relative importance of skilled teaching on the one hand and the generous provision of premises and equipment on the other. In ideal conditions good teaching is backed by good buildings and equipment.

Clearance of old fittings—It is usually possible, with ingenuity, to adapt old buildings, once used for other purposes, for use in teaching science. But the rooms should first be stripped of all their furnishings and the arrangement of the science equipment thought out unhindered by the existence of fixtures left by a previous user.

First essentials—Earlier in this chapter the desirable features of rooms for science teaching have been described. The same standards should be kept in mind when adapting rooms not originally designed for that purpose, even though some compromise is usually inevitable. The basic essentials must first be decided upon and obtained, if necessary, at the expense of less important, though desirable, items. In the following list the most important features are mentioned first.
(*a*) The rooms chosen for practical work must be big enough. Both discipline and efficiency suffer when pupils try to work in cramped quarters.
(*b*) The rooms must be light, with plenty of windows. (The nearer the school to the equator, the less important is the north or south aspect of the larger windows.) Rooms can be made lighter by using light-coloured distemper, or even whitewash, to cover wall surfaces.
(*c*) If existing ventilation is insufficient, adequate arrangements must be made.
(*d*) Store rooms are essential.
(*e*) A piped water supply and an efficient drainage system are required.
(*f*) Some method of providing heat for experiments must be devised. If neither coal-gas nor petrol-gas can be provided it may be necessary to fall back on burners using methylated spirit, or ordinary petrol, or kerosene. Of the latter there are suitable types operating on the principle of a blow-lamp.
(*g*) A preparation room should be provided.

(*h*.) Arrangements should be made to permit one room to be darkened when necessary.

(*j*) Each room should have more than one exit.

Given the above facilities, the arranging of furniture and fixtures should not provide any special difficulty.

Employment of local craftsmen—In some districts there has been a sudden demand for the teaching of science in schools. As a result people have sometimes imported benches, elaborate fittings, complicated apparatus—perhaps because they have seen a picture of an extravagantly equipped laboratory—in the delusion that this constitutes 'science', as though science were some remote, foreign magic. Such an attitude can be prevented, or soon corrected, by a conscientious and enlightened teacher. He will show that science has relevance to the immediate surroundings of the pupils, to the daily life of the community, wherever it may be and whatever stage of development it happens to have reached. So the community itself, as far as the skill of its local workers permits, should have a hand in the construction of laboratory furniture and equipment. This is just as desirable as the construction and improvisation of apparatus by staff and pupils. It is not merely an economy measure: it helps to dispel false notions of science as an alien affair of mysterious devices. Locally made equipment may possibly be less elaborate and appear less imposing, but it frequently leads to a better understanding of science and its methods.

Adapting a classroom for use as a demonstration or lecture room—It is hardly possible to use as a laboratory a room which has to do duty as an ordinary classroom. But such a room may be turned into a demonstration or lecture room, though lack of laboratory facilities may result in pupils being denied the opportunity of doing adequate practical work. However, if it is impossible to have a laboratory, a classroom adapted for giving demonstration lessons is the next best thing.

It is not easy to design a laboratory, and even more ingenuity may be required to adapt an existing classroom for science teaching. Classes vary in numbers; classrooms vary in size, in the positions of doors and windows, in the ease with which piped water can be brought into them and waste water drained out. Each room provides its own problems. If the room is small it may not be possible to include desirable fittings or fixtures, or the width of benches may have to be reduced, and wall space may be very limited. But a room already too small for an ordinary class will certainly not accommodate that same class when adapted for science teaching.

Figures 26 and 27, pages 186–7, suggest how square and rectangular rooms might be planned.

Laboratory fittings and fixtures

Benches—Movable benches may have some advantages in that the laboratory can be rearranged according to varying needs. In practice, however, such rearrangement rarely takes place. Fixed benches, being more rigid, are less likely to be jerked by a class of pupils, and apparatus placed upon them is less likely to be broken. The more sensitive the apparatus the more essential it is that it shall be placed upon a rigid support. Further, water and gas fittings can be permanently fastened to fixed benches. Bench legs can be screwed to a wooden floor by means of small angle brackets. They can be fixed to a concrete floor by being screwed to short projecting pieces of iron strip embedded in the cement.

A suitable height for a working bench is 2 feet 9 inches. Those used exclusively for chemistry should not be lower than this. But as a 2 foot 9 inch bench is rather high for pupils using microscopes it is desirable to have a special bench or shelf for this purpose, about 2 feet 3 inches high, and preferably in front of a window.

Bench tops may be made of boards of any local hardwood. A thickness of 1 inch will serve, but 1¼ to 1½ inches is better. They can be kept resistant to water by being rubbed occasionally with a mixture of linseed oil and turpentine in equal proportions, or with a wax polish.

For the sake of good discipline it is advisable to have narrow benches, 2 feet wide, with all pupils normally facing the teacher's demonstration bench. If one laboratory is used for all purposes then the benches should be thus arranged. But biology or physics experiments sometimes require more space, and the advantage of benches 3 feet 6 inches wide then become apparent. With the narrow

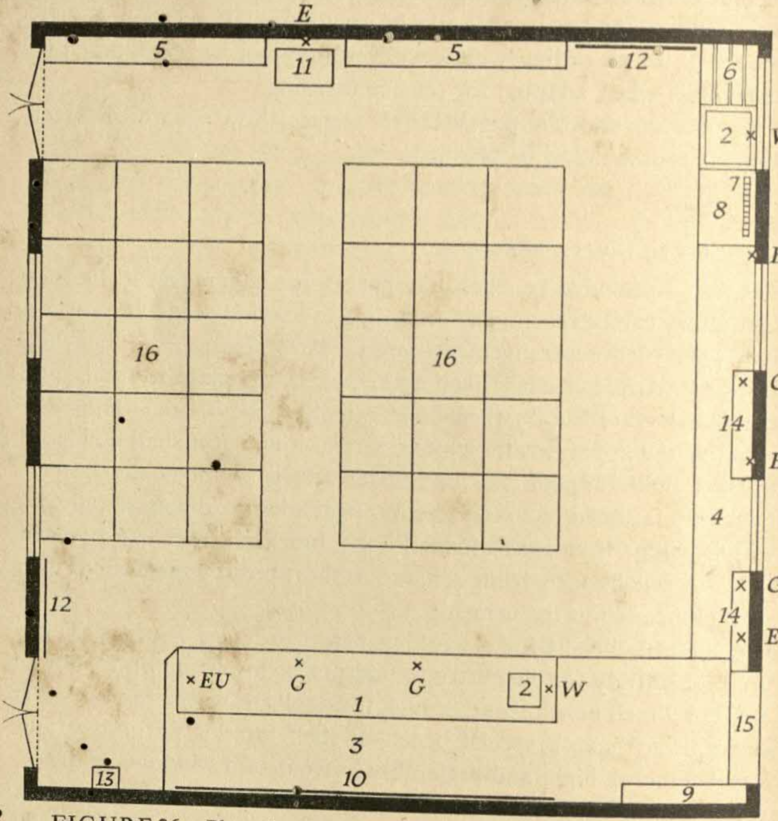

FIGURE 26.—Plan of a square class-room (24′ × 24′) adapted for the teaching of science

EXPLANATION

× EU Electric 3-pin socket and plug fixed under edge of bench (15 amp.)
× E Electric 3-pin socket and plug (15 amp.)
× G Gas point, two-way
× W Water-tap
1. Teachers' demonstration bench, 2′ 9″ high. Drawers (one about 3′ wide) underneath. Cupboards below drawers. Cupboard doors wood-panelled, narrow
2. Sink
3. Dais, 8″ above floor level
4. Long bench, 2′ 9″ above floor. Drawers and cupboards fitted below
5. Cupboards, glass fronted, fixed to wall. Bottom of cupboard 3′ above floor, top of cupboard 6′ above floor. Cupboard doors narrow, but shelves continuous (Part useful as 'museum' shelves)
6. Cement draining slab, sloping slightly

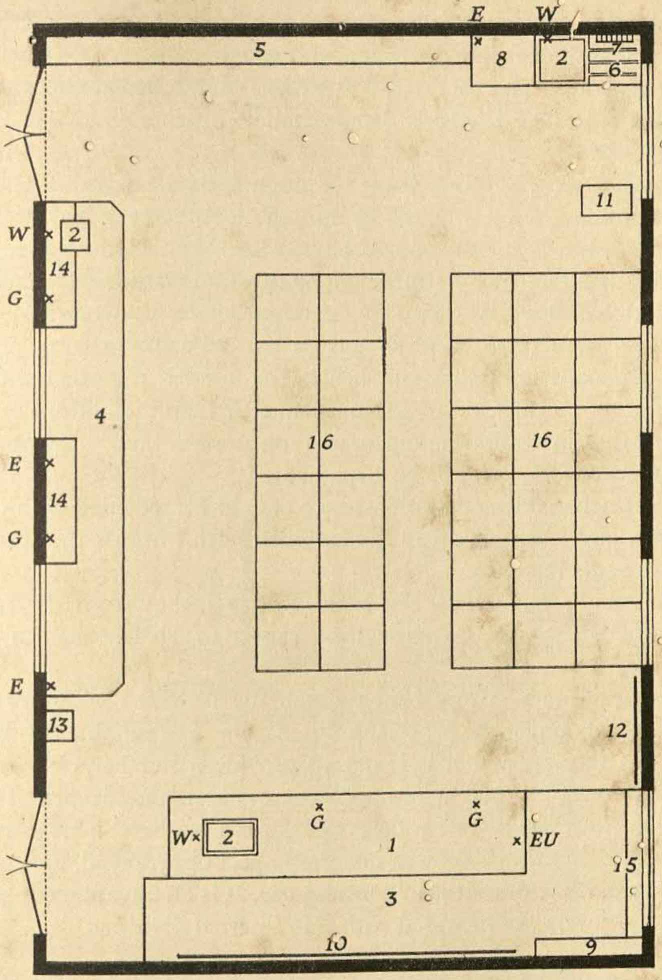

FIGURE 27.—Plan of a rectangular class-room (20′ × 30′) adapted for the teaching of science

EXPLANATION—(*continued*)

7. Drying rack on wall
8. Cement slab, horizontal, 2′ 9″ above floor
9. Open shelves for bottles
10. Blackboard
11. High table, on wheels, for projector
12. Notice or bulletin board
13. Standard barometer
14. Shelves, lower one 18″ above top of bench
15. Low shelf for microscope
16. Pupils' desks and seats

type benches, one sink is needed for each working pair or group. If double width benches are provided one sink will serve two working pairs or groups. This economy is sometimes purchased at the expense of discipline. The teacher's demonstration bench should be 2 feet 6 inches wide.

Bench cupboards—The fitting of cupboards underneath pupils' benches depends on whether or not the laboratory is to be used for chemistry. If so they should be provided. Laboratories used for physics or biology do not need cupboards under students' benches, especially if there is plenty of cupboard space elsewhere. Where cupboards are fitted there should be two to each working place. One cupboard should have a shelf in the middle; the other should have either no shelf, or a shelf much smaller than the bottom of the cupboard, thus allowing apparatus on stands, and long-necked graduated flasks, etc., to be kept in it.

The teacher's demonstration bench should be provided with cupboards, and it is convenient if they open both towards the teacher and towards the class.

Cupboards should be set back 3 or 4 inches from the front edge of the bench, or should be raised to give space for the feet.

Bench drawers—Every bench should be provided with drawers immediately under the bench top. Four inches is a suitable depth for a bench drawer, and it is better to provide a number of narrow, shallow drawers than a few which are wider and deeper. There should, however, be one wide drawer in the teachers' bench. Small apparatus in a large drawer invariably gets disarranged, and often damaged, if the drawer is in constant use. It is an advantage if some of the drawers are provided with thin internal divisions.

Bench sinks—The type usually provided is of glazed earthenware fitted with a safety overflow device. This device may be part of the sink itself. Alternatively, a cylindrical tube, made of either plastic or non-corrosive metal alloy, and shorter than the depth of the sink, is used in the place of a plug. (A piece of brass or lead piping of suitable size might be cut and filed to serve the same purpose.) 12 × 12 × 8 inches (outside measurement) is a suitable size for a sink for students' benches. For a demonstration bench, a sink

18 × 12 × 8 inches is more appropriate. (Sinks in preparation rooms, and one sink in each laboratory, should be 30 × 18 × 10 inches.)

The sink should lie just under the top of the bench, so that the bench overlaps its edge. A drip ledge, made by cutting a groove around the under-edge of the hole in the bench top, prevents water that is washed into the sink from the bench, from running back under the bench top (see Figure 28).

In a laboratory used exclusively for physics or botany sinks are not required in students' benches, but they are necessary for chemistry. In an all-purpose laboratory, therefore, sinks should be provided in students' benches. In this event it is convenient, although not an ideal arrangement, to fit water taps which can be hinged down into the sink. The sink can then be provided with a wooden cover, to fit flush with the bench top. With the cover in place the bench becomes more suited for many physics and biology experiments.

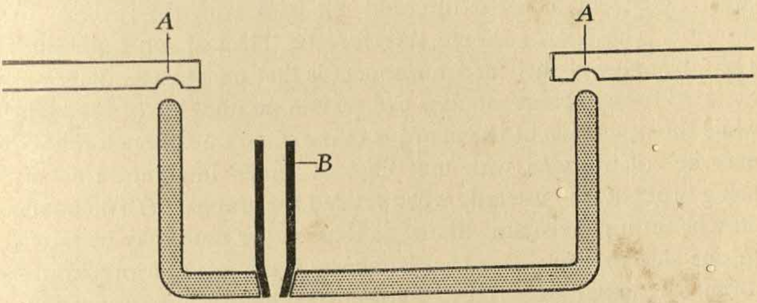

FIGURE 28.—A laboratory sink, with:
A—groove below edges of bench top to form drip ledge
B—safety plug, i.e. combined plug and overflow pipe

Blackboard—Size: It is difficult to imagine a blackboard which is too big. Far too many are absurdly small. An area 8 feet to 12 feet wide and 3 feet from top to bottom is satisfactory.

Position: The blackboard should be fixed to a wall without windows—the shorter wall in an oblong room. The wall should be chosen so that a pupil looking at the blackboard has most light on his left side. The bottom edge of the board should be 3 feet above the floor on which the teacher stands.

Construction: A blackboard may be made of various materials.

(1) A concrete surface, carefully cement-washed, laid flush on the wall itself, has the advantage over all other types in being cheap, unaffected by weather, and indestructible. (2) It can be made of well-seasoned tongued and grooved boards fixed to the wall. (3) It may consist of two or three pieces of plywood, framed in hardwood. A blackboard of this kind may be mounted in various ways. (*a*) The separate boards may be screwed flush to the wall. (*b*) They may be fastened to a permanent wooden fixture which allows the top of the board to overhang the bottom by about 2 inches. This reduces the likelihood of blackboard 'shine'. (*c*) They may be set up as in (*b*), but kept in place by means of turn-buttons, so that they may be easily taken out of the fixture and put back with the reverse side showing. The boards should therefore be 'blacked' on both sides. The advantage of such an arrangement is that matter, e.g. diagrams, required for a subsequent class can remain on one side of the board while the other side of the board is in use. One side of such a board may be square-ruled with unit lines at 1-inch intervals, this side being brought into use only when needed for graphs. (*d*) The boards may be set up like sliding doors, so that one or both may be moved to one side to give access to a hatchway leading into a preparation room. (*e*) Similar access may be given when boards are arranged in a frame, to move up and down with counterpoised weights as in the case of sash windows. This device is useful when the amount of horizontal wall space is limited.

Fittings: A narrow shelf, with beading along the front, should be fitted along the length of the board and just below it, to provide a place for chalk and blackboard cleaner. Above the board, at one side, it is useful to have hooks for the hanging of charts or a small screen. Similarly, screw-eyes suitably situated in the ceiling, are useful for the suspension of a larger projection screen.

Notice or bulletin boards—Such wall space as remains vacant, after shelves, cupboards, blackboard, etc., have been accommodated, may be covered with notice, or bulletin, boards. Most of the material for exhibition on these boards will be fastened temporarily, by drawing pins or thumb tacks. The boards should therefore be made of planks of some local soft-wood, made proof against ants, termites and wood worm by being treated with some repellant, and framed in a narrow hardwood surround. Rooms in hot countries usually have a ceiling not less than 10 feet above the floor; spaces may be found above top shelves or cupboards where pictures may be hung and charts and diagrams displayed.

Boards may also be fastened along any outer blank wall which is sheltered by a verandah. It is not necessary to protect such boards by covering them with glass doors, as the outer walls are not places for the display of valuable or irreplaceable material. When display material has begun to disintegrate, as a result of exposure to wind and weather, it has obviously been on the wall too long, and should have been replaced by fresh material long before. The interest aroused by newspaper cuttings, illustrations from magazines, charts, will give place to boredom, if the same items are displayed too long. Frequent changing of illustrative material is sure evidence of an alert and diligent teacher.

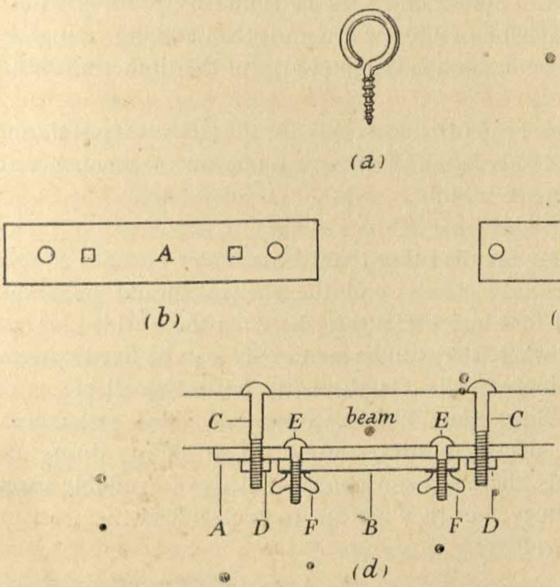

FIGURE 29.—Ceiling fixtures for experiments in mechanics, etc.

(*a*) A screw-eye
(*b*) and (*c*) Small iron plates, drilled as shown
(*d*) Plate A is secured to the side of the beam by bolts C with nuts D. It carries small square-section bolts E, to which plate B is fitted by wing-nuts F

Ceiling fittings—Exposed joists in the ceiling of a laboratory can be very useful. Large screw-eyes (Figure 29 (*a*)), the insertion of which requires no particular skill, may be screwed into ceiling timbers, and from them may be hung individual pieces of apparatus, projection screens, and so on. A series of screw-eyes about one foot apart and set in a straight line can support an iron rod, a wooden bar, or a brass tube, and from such a bar may be conveniently hung various devices to illustrate the laws of mechanics. A useful arrangement for suspending wires or pendulums can be made locally. It consists of two iron plates of unequal length (Figures 29 (*b*) and (*c*)), drilled to take iron bolts, and is fixed to a beam as shown (Figure 29 (*d*)). The two small bolts should have wing-nuts so that the wires can be easily fastened. A competent teacher, or a local carpenter, can set up such fittings as and where they are needed.

If the ceiling is below its supporting timbers, which are then out of sight, the position of the beams must be found by probing with a very fine awl. The shank of a screw-eye must then be long enough to pass through the ceiling and get a good grip of the timber above it.

Clock—If the school can provide a clock for the laboratory it should be one with a seconds hand. There are numerous experiments in which this will prove useful.

Cupboards—All cupboards other than those under benches should have doors with glass panels, and the shelves should be about 1 foot wide and 1 foot apart. Half-way between these wide shelves, at about eye level where they can be seen easily, can be fixed narrow shelves, about 4 inches wide. On these can be put small pieces of equipment, e.g. clips, glass blocks, ammeters, fixed resistances, dropping bottles, density bottles, and so on. If sliding doors are fitted to cupboards, there is a considerable saving of available space in a small laboratory; but they are apt to stick unless they rest on metal strips with rollers.

Dais—The platform upon which the teacher stands, and upon which the demonstration bench is placed, is usually 12 inches above the level of the laboratory floor. It should extend several feet each side of the blackboard, preferably the full length of the wall. When the length of the dais is limited to that of the blackboard, the teacher finds it difficult to stand and write at the ends. A distance of 3 feet should separate the bench from the blackboard.

Draining racks—These vary in size according to the apparatus (test-tubes, flasks, etc.) for which they are generally used. They can easily be made by any carpenter. One should be fastened to the wall by each of the largest sinks.

Fume cupboards—Fewer fume cupboards are required by students following a General Science course than by those following more advanced specialized chemistry courses. The laboratory in which chemistry is taught should have two, the chemistry preparation room needs one, and there should be one in the lecture room. A fume cupboard has a slate or cement base, at bench height, measuring about 3 feet wide by 2 feet 6 inches deep. On this is erected a glass-sided case with a glass top. The front is a glass-panelled sash, kept in any position by weights. A flue must lead from the inside top of the cupboard to the outside of the building. A forced draught of air can be provided by an electric fan placed in the flue, or by arranging for a flame to burn in it. A gas flame is most convenient, but a small lamp, placed on a suitable ledge at the entrance to the flue, will serve the purpose. If a flame is used, the flue must be substantially made, of brick, cement blocks, or of metal well lagged with asbestos sheeting, great care being taken that no heat from the flue can possibly ignite any woodwork. When the cement base is cast, it should include a shallow groove round the edge of the area to be enclosed by the cupboard. If the groove leads into a waste-pipe and thence to the drain, it is easy to dispose of any liquid spilt in the cupboard.

If gas is supplied in the cupboard, the control taps should be outside it.

Electricity for general use—Many experiments require a supply of low-voltage electricity. There are several ways of providing it. (i) A *transformer* connected to a main supply of alternating current (A.C.) can provide a low-voltage current. The usual choice for such a supply is either 6 volts or 12 volts. This current can then be connected to 'two-pin' sockets and plugs conveniently fixed under the ends of individual benches. It is safe to use. It will provide current suitable for 6-volt or 12-volt electric bulbs such as are commonly used for cars. These supply light for experiments with light rays, etc. But the current so obtained is still alternating current, not direct current, and is unsuitable for experiments on electro-magnetic induction, electrolysis, etc., nor can it be used to charge accumulators. Though very useful in a physics laboratory for more advanced students, a transformer is hardly worth the expense of installing in a laboratory used solely for elementary science. If, however, such an installation is provided, it must be remembered that a 6-volt, 24-watt, car lamp uses a current of 4 amps. The electric cable leading to a laboratory wired for a low-voltage supply should therefore be capable of carrying at least 4 amps.

Considerable damage, if not danger, may result from the accidental connexion of apparatus designed for 6 or 12 volts to a high-voltage supply. To avoid all possibility of confusion it is advisable to use 3-pin plugs and sockets for the high- and 2-pin for the low-voltage circuits.

(ii) *Secondary storage cells*, e.g. lead accumulators, or nickel-iron ('Nife') accumulators, supply direct current (D.C.). These are suitable for all purposes, and, if single cells are available, the current may be used for either torch bulbs or car lamps. 'Nife' accumulators are better than lead accumulators for school use. The fluid they contain is caustic alkali (*not* sulphuric acid), they are lighter to carry, and they will withstand harsher treatment without disintegration of the plates.

Accumulators need to be charged from time to time. If mains A.C. is available, an apparatus for charging accumulators should be fixed to a wall, preferably in a preparation room. Such chargers, which are also rectifiers and so provide direct current, are supplied complete with ammeter and resistances for measuring and regulating the rate of charging. With the aid of such a battery-charger and reasonable care, a collection of accumulators can be kept in working order for years.

Very inexpensive 'trickle chargers' are also obtainable. These provide a much smaller current, so the charging process takes longer. But they are efficient and fool-proof. Accumulators should never be charged at a rate higher than that recommended by the manufacturers. At this rate they cannot be spoiled if left on charge for too long. All that happens when they are fully charged, i.e. when the chemical changes in the plates are complete, is that the liquid (acid or alkali) is electrolysed, yielding oxygen and hydrogen. Thus addition of distilled water replaces any loss.

(iii) *Primary cells*, such as quart-size *Leclanché cells*, also provide direct current suitable for most experiments. But it must be remembered that their output is more variable than that of accumulators, and the current falls off when they are used continuously for more than a few minutes. During the chemical action which produces the current, the zinc poles dissolve and the ammonium chloride in solution is slowly replaced by zinc chloride. But zinc poles and ammonium chloride are cheap and obtainable with reasonable ease, and their renewal, as required, ensures a long life for each cell.

Other types of primary cells, e.g. Daniell, Bunsen, bichromate, etc., are not suitable.

(iv) *Dry batteries* do not differ in their output from Leclanché cells. They have a surprisingly long life, if used for short periods of intermittent current, but when they have run down they cannot be recharged, nor can their parts be replaced, and so they are of no further use.

Methods (ii), (iii) and (iv) have one great advantage over method (i) for elementary science teaching: there is constant need to decide how many cells are required for any experiment, and how best they should be connected. To provide a greater voltage, cells have to be connected in series; to increase the current, more cells must be added in parallel. Experience in the use of cells, therefore, emphasizes the meaning of the fundamental characteristics of an electric current. This emphasis cannot be gained from the uncritical use of a 'laid-on' low-tension supply.

High-voltage points, if a mains supply is available, should be provided at the teacher's demonstration bench (15-amp.); along the side-benches (15-amp.); and by any shelf upon which microscopes are to be used (5-amp.). Additional points for providing current for a still (15-amp.), an aquarium aerator (5-amp.), a klinostat (5-amp.), a projection microscope (5-amp.) and a projection lantern or epidiascope (15-amp.), are needed at the appropriate places. The capacity of the sockets and plugs required is given in parentheses.

It is unwise to plug in apparatus by means of adaptors to light sockets, and this should be forbidden.

Each 15-amp. socket should have its own fuse, either near by or on the main switchboard.

The bared ends of wires attached to a 220-volt mains supply can give a careless user a fatal shock. All plugs and sockets should be of the three-pin type, with the third pin effectively earthed. Apparatus connected to a mains supply should not be manipulated while the current is switched on. A control switch of the appropriate capacity should be provided for each socket.

Possible danger in the use of electricity—From the start, when the chemical sources of current are first described, the value of the voltage produced should be stated (see Appendix J, page 364). An appreciation of the practical meaning of voltage is thus built up. Domestic installations are arranged to provide supplies up to about 250 volts. Fatal accidents may occur if the body is subjected to voltages of no more than 80 to 100 volts. But the amount of current matters as well as the voltage. The bare end of the wire leading to the sparking plug of a car, if touched while the engine is running, will give a powerful shock, for the voltage is of the order of several thousand volts. The experience is momentarily painful, but not likely to prove fatal because the current is very small. But the shock received by someone standing, for example, in water in a metal bath fitted with pipes buried underground, who touches with a wet hand the exposed points of a mains electric device, thus making good contact with both earth and 'live' wire, will probably prove fatal, though the voltage be only 110.

The teacher must always make sure that any possibility of danger is reduced to a minimum, that any pupil using the electric supply knows exactly how to proceed, and that every member of his class knows the reasons for taking the necessary precautions.

Hints on wiring additional lamps and sockets—The following information may be of use to a teacher who wishes to provide a laboratory with extra electric lamps or sockets and intends to wire them in himself.

Two wires come from a mains supply to the meter board. One is the

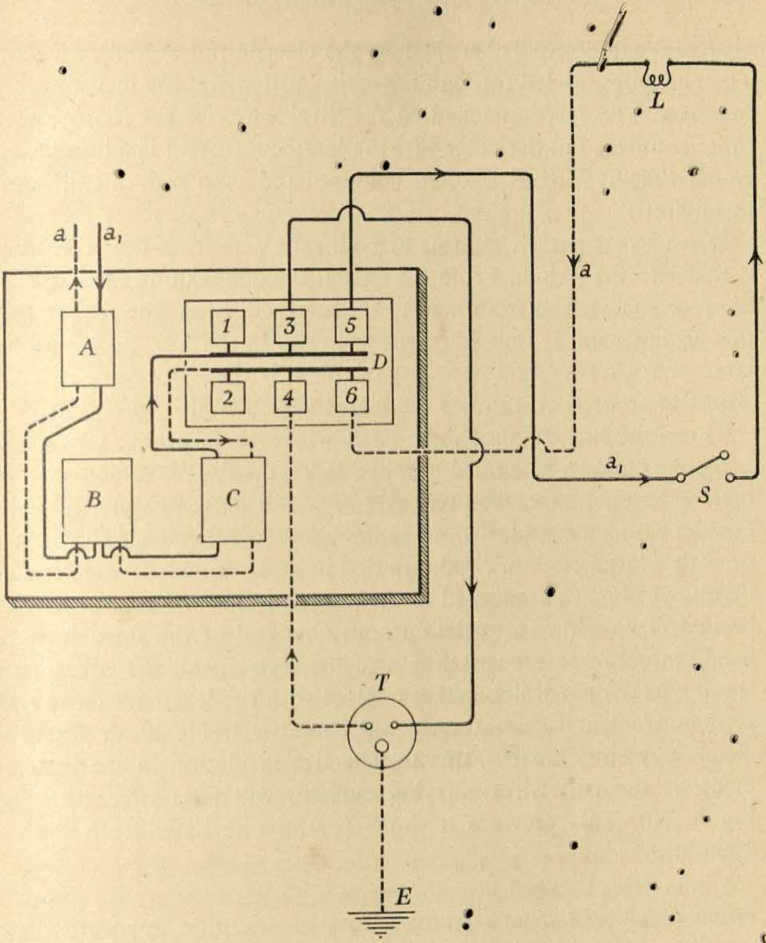

FIGURE 30.—Meter board and electric wiring

A—Mains fuses (not to be touched)
B—Main switch C—Meter
D—Fuse box
1, 3, 5—'live' fuses
2, 4, 6—'neutral' or 'earthed' fuses
E—Earth
L—Lamp S—Switch T—Three-pin socket and plug
a—'Neutral' or 'earthed' wire a_1—'Live' wire

Note—It is a particularly opportune time for pupils to study the electrical system when a new circuit is wired up in the laboratory.

'live wire', the other is 'earthed' at the electric power station itself. The two wires are led through the mains switch and the meter to the fuse box. The fuses attached to the 'live' wire are the 'live' fuses, those connected to the other wire are 'earthed' fuses. (The insulation round the 'live' wires is often coloured red or a red thread runs through it.)

When a new electric point is wired in, the wire from the 'live' fuse is taken to the switch. From the switch the connexion is led to the lamp or socket, and from here to the 'earthed' fuse. The reason for this arrangement is that when the switch is in the 'off' position the lamp or socket is 'dead'. In spite of this it is wise practice never to adjust lamp or socket unless the mains switch is also turned off.

Three-pin sockets should be used wherever possible. Two pins carry the current. The third terminal is 'earthed'. It is attached to a piece of copper wire, the other end of which makes good electrical contact with a water pipe which somewhere else is buried in the earth, or with a large piece of copper buried in moist earth. Any electrical instrument is then connected to the plug as follows. Three wires are needed. Two wires carry the current. One end of the third wire is firmly attached to the metal case of the instrument, the other end leading to the pin which makes contact with the 'earthed' terminal. It is convenient to use three-cored cable or treble 'flex'. By this means any stray current, due to defective insulation in the instrument or the two wires carrying current, will pass to earth (see Figure 30). This prevents a shock for anyone handling a faulty apparatus.

Fitted boxes and trays—Many pieces of scientific apparatus are fragile and require care in handling and storage. The use of shallow wooden trays or cardboard boxes for small items helps to reduce the risk of breakages. Trays for crucibles, density bottles, etc., should be divided into compartments by strips of plywood or cardboard. Thin strips of cardboard, folded and kept in shape by paper staples as shown in Figure 31, make satisfactory protective divisions in trays or boxes for lenses and mirrors. A system of this kind is not only a safety measure but is the simplest way of ensuring regular and rapid checks of the number and condition of articles.

Reagent shelves fitted to benches are satisfactory in a chemistry laboratory, where sets of bottles are in frequent use. In a General Science room it is better to keep the benches clear. The sets of reagent

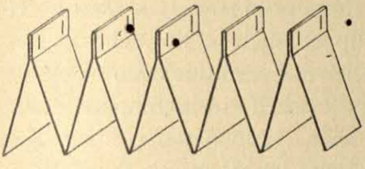

FIGURE 31.—A simple method of storing mirrors and lenses. (A strip of cardboard is folded and pinned to provide compartments in a tray)

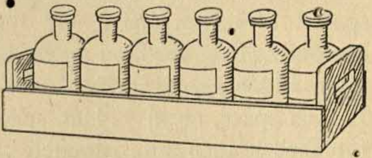

FIGURE 32.—A wooden tray for the storage of reagent bottles

bottles may be kept in wooden trays with handles (see Figure 32). These are easy to store in cupboards, and can readily be put out at appropriate places on the benches when required.

Hooks, clips, etc.—Space in cupboards can often be saved by fixing a row of pegs or cup-hooks (screw type) in suitable places. They are convenient for hanging small pieces of apparatus, such as spring balances, thus leaving the shelves free for larger items. Spring clips of assorted sizes are also useful. They can be screwed, where necessary, into any vertical board, e.g. the side of a set of shelves, to hold apparatus, illustrative material, notices, etc.

Shelving—Open shelves for bottles containing liquids need be no more than 6 inches wide. A beading along the front edge of the shelf is not necessary, but a narrow strip, about ½ to ¾ inch wide, placed along the back edge of a shelf or bench top, prevents undue staining of the wall behind. If the floor of the room is of cement, the bottom shelf should be 16 inches above it. This allows large bottles (such as Winchester quarts), 14 inches high, to stand on the floor. If the floor is of wood, the bottom shelf should be at least 4 inches above it, to allow the space beneath to be cleaned. Upper shelves should have about 8 inches space between them. Lower shelves can be spaced more widely. Measuring from the floor upwards, shelves 1 inch thick, can be placed thus: 4-inch space, shelf, 16-inch space, shelf, 12-inch space, shelf, 10-inch space, shelf, 8-inch space, shelf, 8-inch space, shelf, 8-inch space, shelf. The top shelf is then just over 6 feet above the floor, and is quite high enough.

Open shelves for bottles containing solids should be about 8 inches wide, without beading in front. The bottom shelves should be spaced 14 inches apart, and the upper shelves 12 inches apart. Measuring from the floor upwards, shelves 1 inch thick can be placed thus: 4-inch space, shelf, 14-inch space, shelf, 14-inch space, shelf, 12-inch space, shelf, 12-inch space, shelf, 12-inch space, shelf. The top shelf is then approximately the same height above the floor as in the previous case.

Chemical balances must be supported on a rigid shelf, preferably 18 inches wide, and 3 feet 3 inches above the floor. A cement slab is better than a wooden bench. A length of 2 feet of bench is required for each balance.

If large bottles, or aspirators, are used to provide a store of the commonest bench reagents, the shelves should be 1 foot wide, and not more than 3 feet 6 inches above the floor.

Shelves arranged in racks for use in a store room should not be more than 3 feet wide. Access should be possible from both sides. A distance of 15 inches between the shelves is suitable, though shelves which are at about eye level can be a little closer together.

In a store room chemicals may be arranged alphabetically or according to some other system. Whatever method of storage is adopted, the quantity, and size of container, of one chemical often vary greatly from those of the next. Shelves around the walls, therefore, cannot well be less than 14 inches apart.

Glass rod and tubing can be stored horizontally, but a vertical rack, in which they stand on end, is more economical of space.

Water taps—Each sink on the students' benches should be provided with a water tap, the nozzle of which should be suitable (buttress riffled) for attaching rubber tubing. It should, if possible, be not less than 18 inches above the bottom of the sink. Sinks on teachers' demonstration benches should be provided with a fitting which has three nozzles, two of small diameter and lower than the third, which can be slightly larger. All three nozzles should be adapted for attaching rubber tubing, and the larger nozzle should be 2 feet above the bottom of the sink. Sinks in preparation rooms each require at least one large tap, with a nozzle of anti-splash type, which should be at least 2 feet above the level of the sink. With the tap set at this height, and a sink of the size recommended, it should be possible to wash burettes without spilling water over the floor.

Note—First-aid and the kit required are discussed with the prevention and treatment of accidents in Chapter XI, page 278, and Appendix H, page 349.

CHAPTER X

Aids to Teaching

No wise man refuses help and no wise teacher ignores 'aids'. They come from many quarters. These aids, as the title of the chapter implies, are to help *in* teaching, not to be substitutes *for* teaching, nor for teachers. The problem that faces administrators, how to provide for the education of too many children with too few teachers, is not likely to be solved by the liberal provision of mechanical 'aids'. But teaching by their help is likely to be all the more effective.

Aids should be handled with discretion: they must be kept in their proper place. They have to be woven into the pattern of activity the teacher desires, and not allowed to determine, because they are available, what shall be learnt, and when. Aids are a supplement to teaching, bringing up-to-date and expert knowledge to the class-room. They often arouse as many questions as they answer; and this is a good thing. They can stir the imagination by demonstrating the practical uses to which scientific knowledge has been put, or arouse a sense of wonder at the beauty and variety of nature in the world in which we live. It is a common experience to search for illustrative material from distant places and fail to find it, overlooking the illustrations that lie near to home. The teacher should first seek out, and put to good use, the material he has at hand. If he fails in this, he is not likely to make good use of material brought from far afield.

The less fuss made about the introduction of illustrative material the better. The more rearrangement of seats, and general dislocation of ordinary class routine, the more detached from the subject does the material tend to become. This is the opposite of what is desired, especially in the use of film-strips, films, and projection material generally. If such aids are used they should be in place before the lesson begins, and blinds should be fastened so that they can be released in the minimum possible time. Then, almost before they realize what is happening, the pupils are being presented with the illustrations, so that there is no tendency for the latter to become dissociated from the rest of the lesson.

Apparatus and materials

The science teacher has an initial advantage over the teachers of other subjects because so many of his lessons may be illustrated with concrete material. The apparatus at his disposal, variously connected and arranged, is continuously available.

One of the first tasks of a teacher is to make sure that his material is kept, as far as possible, in full view of his pupils. Models, pieces of apparatus, specimens in jars, etc., may be put in glass-fronted cupboards, or on open shelves, and clearly labelled, so that even the pupil whose attention temporarily wanders is still confronted at every turn by named articles. The more delicate apparatus should be kept in the cupboards. *One* density bottle, *one* overflow (Eureka) can, *one* calorimeter, etc., can be placed on a shelf, on the edge of which the name of each article is plainly printed. The remainder of the bottles, cans and calorimeters, etc., can be put away in cupboards with wood-panelled doors.

Plainly labelled bottles of the chemicals in common use should be on open shelves in the laboratory, so that all pupils may see them clearly. Chemicals supplied in dark-coloured bottles cannot be seen, so some of the contents should be put into plainly labelled, clear-glass bottles, and placed on the shelves. (The coloured bottles, containing most of the stock, should be kept in the store.) Even if it is never deliberately brought to his attention no pupil should be able to avoid knowing, for instance, that copper sulphate crystals are blue and ferrous sulphate green.

The blackboard

The blackboard is the commonest of all visual aids, and is, in fact, such a commonplace of classroom teaching that it is rarely used as effectively as it might be. The science teacher should never be without a supply of coloured chalks. With their aid parts of a diagram needing emphasis can be brought into prominence. A diagram of the human chest and abdomen becomes clearer and more memorable if the lungs, heart, liver and intestines are shown in different colours, with correspondingly coloured labels. A diagram of rays of light, reflected or refracted, is made much plainer if individual rays are of different colours. Their tracks through various optical instruments can be more clearly shown. It takos no more time to draw a plant and its roots using green and brown chalks for leaves and roots, but the result is more impressive than a drawing in white chalk.

The teacher's blackboard work should encourage neatness, clarity and accuracy—all the virtues he hopes to find in his pupils' records. Other uses will occur to the teacher, such as: the underlining of important stages or main principles in an argument or calculation; putting estimated values of errors and calculations of percentage error alongside experimental results; and stressing corrections, e.g. for temperature and pressure of a gas, water equivalent of a calorimeter, etc.

Models and charts

Charts and models of biological interest may be obtained from suppliers of biological materials. Most firms which supply science equipment also furnish models of machines, pumps and engines, etc. The large firms whose products are advertised all over the world, such as manufacturers of chemicals, all kinds of electrical equipment, engines and motor-cars, etc., usually have special departments which deal with inquiries for illustrative materials useful for schools. They will often supply these materials free of charge. Government departments, particularly agricultural departments, often have illustrative material which they are glad to supply to schools. Requests for such aids should be made either direct to the department concerned or to a Public Relations officer, and a teacher should make inquiries of such sources in his own country.

It is part of the duty of any science teacher to make models, charts and diagrams. Among the most continuously useful visual aids for teaching purposes are those the teacher makes for himself. Moreover, his pupils should be encouraged to help, and to make such aids as a hobby, especially in science clubs, handicraft groups, etc.

Other available aids

There is hardly any object, device or activity that cannot in some way contribute to the learning and teaching of science—which is one good reason for including the subject in the school curriculum. It is convenient, however, to classify 'teaching aids' as in the following paragraphs. Those generally accepted in everyday school work are given first, but some of the others may provide the inspiration for genuine education in science.

Memory aids—There are many ways of helping pupils to remember important facts and useful data. The methods usually depend upon creating some kind of interesting link, perhaps amusing or even nonsensical. Pupils may be encouraged to make up original 'aids', for the concentrated attention required in their construction is in itself a help to the memory. Here is a random list of examples:—

(1) *Alphabetical arrangements*. The order of letters in the alphabet may be used to fix in the mind such facts as the following:—

(*a*) 'Acids' (*Ac* . . .) comes before 'Alkalis' (*Al* . . .) alphabetically; '*B*lue' comes before '*R*ed' alphabetically.

Thus 'Acids' and 'Blue' are linked together, and we get:—

$$\begin{tikzcd} Ac \arrow[dr, dash] & Al \\ B \arrow[r] & R \end{tikzcd}$$

'*A*cids turn *B*lue litmus *R*ed'

(*b*) Stala*ct*ite (hangs from roof, so we remember *c* for *ceiling* or *t* for *top*).

Stalagmite (on the *ground*, so we remember *g* for *ground*).

(2) *Acrostics*. A list of words (or lines) may be arranged so that their initial letters form a word—real or invented—thus making it easier to remember the list:

(*a*) Important properties of a gas include:—

C ombustion	(the gas does or does not support)
L itmus	(reaction of the gas to)
O dour	
U	[= 'hue'! = colour]
D ensity	(compared with air)
S olubility	(in water)

'CLOUDS', made up by the initial letters, sometimes helps a pupil to remember the items in the list.

(*b*) The colours of the rainbow are:—

Red	R ichard
Orange	O f
Yellow	Y ork
Green	G ained
Blue	B attles
Indigo	I n
Violet	V ain

Or as an alternative, reading the initial letters upwards: 'VIBGYOR'.

(*c*) The characteristics of living organisms are:

M ovement
E xcretion
R espiration
R eproduction 'Not Herring, but "MERRING" '.
I rritability
N utrition
G rowth

(3) *Characteristics by numbers:—*

THREE—(*a*) Of a taut string affecting the pitch of the note:

LENGTH TENSION THICKNESS

(*b*) Of a musical note:

PITCH AMPLITUDE QUALITY

(*c*) Of wave motion:

FREQUENCY WAVE-LENGTH AMPLITUDE

THREE PAIRS—Of images in mirrors:

REAL	ERECT	ENLARGED
or	or	or
VIRTUAL	INVERTED	DIMINISHED

(4) *Summaries and exceptions:—*

(*a*) Non-metals are non-conductors—NOT CARBON
(*b*) Dilute acids on metals yield hydrogen—NOT NITRIC

(5) *Rhymes*. Some pupils enjoy nonsense verses as a means of

remembering facts. For example:—

Sir Humphrey Davy
Abominated gravy,
And lived in the odium
Of having *discovered sodium.*

Poor little John is dead and gone,
You'll never see him more:
For what he thought was H_2O
Was H_2SO_4.

(6) *Miscellaneous*—

(*a*) Formation of shadows:

'Point' suggests something 'sharp'.

Hence we may remember:

'A *point* source of light gives *sharp* shadows.'

(*b*) Density:

$$\text{grams per c.c.} = \text{g.} / \text{c.c.} = \frac{\text{weight}}{\text{volume}}$$

Charts and diagrams—Charts and diagrams are useful for the immediate illustration of lessons, and should be hung by the side of the blackboard rather than over it. (For the same reason a projection screen for small pictures should be placed at one side of the blackboard. A large screen may have to be hung over the blackboard itself, but the blackboard is so valuable an aid to teaching that interference with its use should be kept to the minimum.) When they have sufficient general interest they may well be displayed on a notice board, or on the wall of laboratory, verandah, corridor, or covered way.

Graphs are in such common use and so readily display variations in values, that pupils should be encouraged to employ graphical methods whenever possible. Regular variations are shown particularly clearly by means of graphs, and this point may be emphasized by drawing charts showing more than one cycle of events. For example, graphs showing average maximum temperatures, or average rainfall, for each month, can be extended to show the records

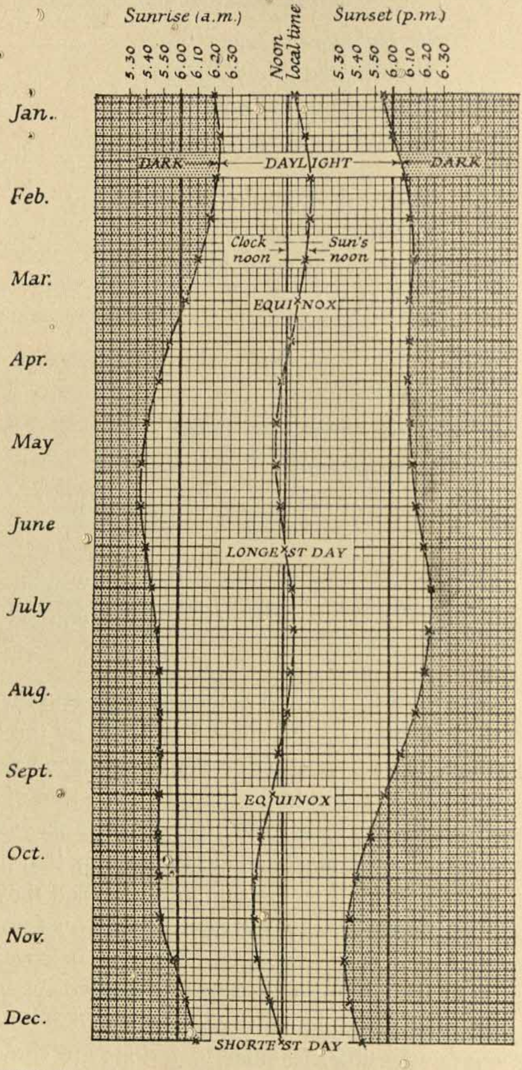

FIGURE 33.—A graph of times of sunrise and sunset: for a place in latitude 10° N. (A useful and typical example of periodic variation in nature)

for several years. The repetitive influence of the seasons can be more obviously correlated, for instance, with annular rings on trees, than is possible when only one year's records are considered.

In addition to the usual weather records, suitable graphs, for construction by teacher or pupils, include those showing times of moonrise, or high tide, and the declination of the sun or the moon. All show periodic variation. Their construction and display help to emphasize the *rhythm* which nature so often exhibits. The appropriate data can be obtained from *Whitaker's Almanack*, the *Nautical Almanac*, or similar publications. A graph showing the variation in the times of sunrise and sunset throughout the year at places in any given latitude provides a welcome and instructive change (see Figure 33).

Charts and diagrams should not remain on notice boards until they are faded or in poor condition, as pupils soon lose interest. It is better to put them away and display them again after an interval of a few months.

Projection apparatus

(*a*) *Epidiascope*—This apparatus projects an image of any flat, opaque object, such as the illustration in a book, a diagram, a pressed specimen, and so on. In this manner it works as an *episcope.* By the movement of a lever the projector can be used to project slides, films, and similar flat, transparent material. In this manner it works as a *diascope.* The area of the projected picture is usually larger than that provided by a film strip projector (see next paragraph), and is thus suitable for larger rooms. But the episcope requires a very bright illuminant, and nothing less than an electric light of 1,000 watts is satisfactory. Because such a lamp dissipates a great deal of heat, the design of the apparatus must allow for adequate cooling. This may be ensured by ventilation through slits, and if necessary using an electric fan. Its use normally requires a darkened room, and a mains electricity supply is essential.

In one respect the old type of projection lantern is sometimes more convenient, for it can be illumined by a burner supplied by acetylene from a portable generator. Unfortunately this older type is not suited for use as an episcope.

(*b*) *Film-strip projector*—In place of the old-fashioned projection lantern, with its 3¼ × 3¼-inch glass slides, there are now available much smaller lanterns which use a strip of film on which successive pictures are printed. Each 'strip' is conveniently packed and stored in a small metal case about the size of the container of a '120' or '620' camera film. The size of the projected picture is usually up to about 2 feet by 3 feet, large enough for a class, but hardly large enough for a school assembly room. The room in which the apparatus is used should be darkened.

The apparatus uses an electric lamp. This may be supplied with a current either—

(*a*) from an A.C. mains supply through a transformer;
(*b*) from a D.C. mains supply using a resistance;
(*c*) from a 12-volt, large capacity car-type accumulator.

It is an advantage if the apparatus has an arrangement enabling the film to be turned through a right-angle, so that the projected pictures, which are rectangular, can be shown in either a horizontal or a vertical position.

(*c*) *Micro-projector*—This apparatus enables a microscope slide to be projected either on to a vertical screen, so that a whole class can see it together, or horizontally on to a bench. If a piece of paper is placed on the bench and the image projected upon it, a tracing of the image can be made.

It is best to darken the room in which the apparatus is used. If the size of the image is more than 1 foot across, and the magnification is more than × 20, it is not bright enough to be seen clearly by a pupil more than 12 feet from the screen.

Illumination is provided in the same ways as for a film-strip projector.

(*d*) *Cine-projector* (*substandard: silent or sound*)—A projector for silent films is far less costly than one for sound films, although the optical arrangements are the same. A sound projector can be used for silent films, but not vice versa. The substandard size, useful for class-rooms or small halls, is rated as '16-millimetre'.[1] Cine-projectors are quite easy to use, but it is advisable for a school to have one member of the staff to operate it and be responsible for it. (Such a teacher should be given facilities for learning how to use the apparatus under the instruction of a skilled operator on several occasions before he is left in sole control of the instrument.)

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[1] Films being supplied from U.S.A. to schools in some tropical areas are of the 8-millimetre size, which is standard for schools in U.S.A.

A mains electricity supply is essential. The lamp and motor may be operated direct from the mains, or, as in the case of some film-strip projectors, from an A.C. mains supply using a transformer, or from a D.C. supply using resistances. In the last arrangement the voltage applied to the lamp and the motor depends entirely on the positions of the resistances, whether in series or parallel, relative to them. Great care is necessary, for if any part is short-circuited considerable damage may result.

The room should be darkened when the apparatus is in use.

Film loops—By means of an attachment, cine-projectors can be adapted to project loops of film. Loops are used to show repetitive actions where it is an advantage for the viewer to see the action over and over again. Using the same technique as for an animated cartoon, the artist can produce a detailed sequence of drawings showing, for example, an engine passing through its cycles of movement. If contrasting colours and other devices are used to provide emphasis, the action of particular parts of a complicated machine can be readily followed.

Examples of film loops of particular interest to science teachers are those showing the working of two-stroke and four-stroke internal combustion engines, valves and pumps, the solar system, the action of the heart, and the circulation of the blood.

Film-loops, because they repeat the same actions, are very cheap in comparison with long films of the ordinary type taking an equal time to show.

Notes on projection apparatus

(i) *The electricity supply*—The rating of the mains supply from which it is proposed to work the projection apparatus must always be stated when an apparatus is ordered. The details required are usually: voltage; whether D.C. or A.C.; and the number of cycles (if the current is A.C.). These data can usually be found stamped on the front of the electric meter which controls the supply for the building.

It should be noted that some types of projector may be operated by means of a pressure (kerosene) lamp instead of electricity.

(ii) *Projection screens*—Special screens are available for small sizes of projected image, up to about 3 feet high by 4 feet wide. This type is rolled up in a long, narrow box, out of which the screen may be drawn up, and kept erect and extended by levers. The box acts as a base on which the screen will stand on any flat surface without other support.

Larger pictures require other arrangements. They can be projected on to: (*a*) a plain class-room wall which has been distempered with a light-coloured wash, or with whitewash; (*b*) a calico screen or sheet on which has been put a coating of light-coloured distemper or whitewash. In the case of a large screen, a device is needed for suspension from the ceiling, and for rolling it up out of the way when not in use. A flap of some dustproof material should cover it for protection.

(iii) *Spare lamps*—There is no standard type of lamp and lampholder for the various classes of projection apparatus. Every manufacturer uses his own type. It is therefore advisable to obtain two spare lamps to fit each apparatus at the time it is purchased.

(iv) *Lenses and picture size*—Focusing is carried out by moving the 'objective'—the lens which is nearest the screen. All lenses are rated according to their focal length. The following formula holds good:—

$$\frac{x}{f}=\frac{y}{d}$$

where x = the width of the original picture or object
f = the focal length of the lens
y = the width of the projected picture
d = the distance of the projected picture from the apparatus.

a and b may be substituted for x and y where
a = the height of the original picture or object
b = the height of the projected picture.

The size of a may be: 16 mm. for a substandard cine-film[1]
18 to 24 mm. for a film strip
35 mm. for a standard size cine-projector
3¼ inches for a diascope
6 inches for an episcope.

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[1] See footnote on page 210.

The longer the focal length the smaller the picture, assuming the distance from projector to screen remains the same. Other things being equal the smaller the projected image the brighter it is. The larger the projected image the stronger is the illuminant required.

The school museum

It is probably best, in a small school at least, for the science department to keep its own museum. Exhibits of scientific interest are so varied that it is hardly possible to do more than hint at their variety. They may range from bits of submarine cable to a chrysalis, from a pebble to a musical instrument.

Two requisites of a museum are systematic arrangement and good, clear labelling of specimens. Bottled snakes should not be side by side with shells of molluscs, nor a sample of a local mineral side by side with a radio valve.

The amount of information on a label attached to a specimen is often too little. A card 5 inches × 4 inches is a minimum size, and even this is too small for many exhibits. The name (both scientific and common in appropriate cases), and the family to which the specimen belongs (in the case of biological exhibits), should be boldly printed at the top. There should follow the name of the person who gave it, found it or brought it, where and when it was found and such information as to make the reason for displaying it fairly obvious. The information should be written in such a manner that it can be understood by a person with little or no knowledge of science. Technical words and phrases should be avoided in a general or junior museum.

Biological material offers special difficulties in preservation, and is considered in Chapter XI, pages 229, 248–51, 260, 262.

The important thing to remember is that a museum must not be a dull, 'dead and dusty' collection. Not only must it be of interest but it must reflect the pupils' interests. The right sort of exhibits, properly arranged, and used in due season, can be an abundant and rewarding source of teaching material—a 'live' store of examples.

'*Red-letter days*'

Nothing brightens up a class more than a lesson taught with all the skill at a teacher's command and backed up by some unusual experiments—which have required much preparation. Memorable lessons of this kind can be arranged in connexion with topics such as flames, explosions, brightly coloured lights, living specimens, or anything to which people deeply and instinctively respond.

A lesson on hydrogen may be strikingly illustrated by burning the gas, mixed with a little air, or better still, with some undiluted oxygen, in large test-tubes. A satisfying explosion, which is not dangerous, occurs. A small quantity, say 50 g., of gunpowder may be prepared (the mixture should *not* be made with a pestle in a mortar) on a suitable day, and set alight out of doors. There will be no explosion, but a good flare will result. During the electrolysis of water in a simple apparatus, such as that illustrated in Figure 34, the mixed gases may be bubbled through soap solution held in a pupil's hands. When a match is applied to the bubbles (well removed from the apparatus), there is an explosion which is quite harmless and cannot even be felt. (Willingness to allow the explosion to take place in his hand is some indication of a pupil's courage!)

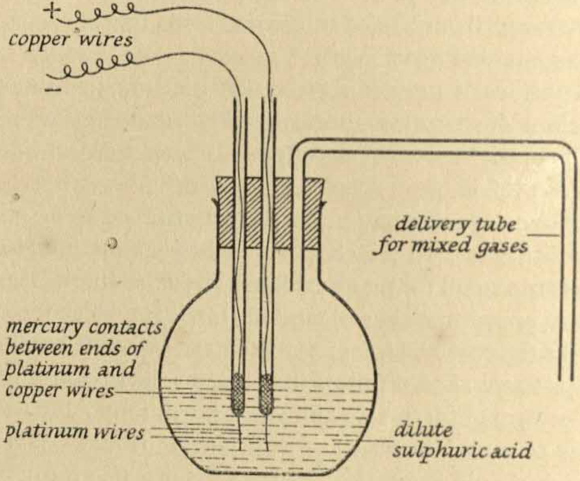
+
copper wires
–
delivery tube for mixed gases
mercury contacts between ends of platinum and copper wires
platinum wires
dilute sulphuric acid

FIGURE 34.—The electrolysis of water: a simple apparatus for the delivery of small amounts of a mixture of hydrogen and oxygen—for harmless explosions

Experiments on colour have a great appeal. When three sources of white light shine through three screens of the three primary colours, a white wall, or a large sheet of white paper, illumined by all three, still appears white. The various shades made from two primary colours only may also be produced. When an object is placed between the lights and the wall, or paper, a variety of coloured shadows is obtained. To account for the various colours not only provides an exercise in clear thinking, but the coloured shadows are themselves most pleasing.

Experiments with living creatures have a particular fascination: e.g. the respiration of small creatures; the examination of the movement of blood in the capillaries of the web of a frog's foot; the destruction of mosquito larvae when oil is sprayed on the surface of the water in a glass-sided tank in which they have been allowed to breed.

A similar stimulation of interest is often brought about by the performance of an experiment on a larger scale than usual. Large bottles (e.g. 3-litre) may replace conical flasks. An impressive effect is sometimes obtained by the mere repetition—not essential, perhaps—of part of an apparatus. For instance, to show that living creatures breathe out carbon dioxide, the air to be purified may be drawn through a wash-bottle of caustic soda, a wash-bottle of lime-water, and then through still another bottle of lime-water to show that all the carbon dioxide has been extracted. After the air has passed through the bell-jar in which the creature is breathing, it may be drawn through a wash-bottle of lime-water, and then a second bottle of lime-water, which will indicate how effectively the first has removed the gas. Five wash-bottles, with contents clearly labelled, and with air bubbling through them, make a more impressive and memorable apparatus than the minimum number of two.

The weekly 'quiz'

This is a scheme by which, once a week, usually on Friday, a question is put on the notice board. To find the answer to it a certain amount of original thinking should be necessary, or it should require the use of reference books. The next week the teacher puts on the board the answer to the 'quiz' and adds another question. In appropriate cases, these weekly quiz questions can be incorporated in competitions for house points. The house whose members submit the greatest number of correct answers gains a weekly house point.

The following are examples of suitable questions:—

(1) Why was A.D. 1900 not a leap year?

(2) Why is October (Octo = 8) the tenth month?

(3) Do other heavenly bodies show phases in the same way as the moon? If so, which?

(4) The date of the Muslim feast of Ramadan comes 11 days earlier in each calendar year. Why is this?

(5) Why is the element polonium so named?

(6) What famous chemist was executed by Revolutionaries?

(7) Find out the names of two great Scientific Societies. Who founded them and when?

(8) Who invented the wheelbarrow?

(9) Why does the application of alum to a cut help to stop bleeding?

(10) Why is carbon monoxide poisonous? Where are ordinary people likely to come into contact with it?

(11) Why must every motor-car be provided with 'brushes' and where are they fitted?

(12) Shakespeare wrote:—

> 'For so work the honey bees,
> Creatures that by a rule in nature teach
> The act of order to a peopled kingdom,
> They have a king and officers of sorts:'

There is an error in this account of the bee community. What is it?

(13) What is the argument in favour of spelling the word 'reflexion', instead of 'reflection'?

(14) A cube of white wood, each edge of which is 3 inches long, is painted red all over. It is then cut into 1-inch cubes. How many of the small cubes will have 3, 2, 1, and 0 red sides respectively?

(15) Under what names can ethyl alcohol, either pure or dilute, be bought in this country?

(16) A dye used for textiles is rarely the same colour as the article appears to be after dyeing. Why is this?

(17) How much sulphuric acid is imported into this country every year? For what purposes is it used?

(18) What is the most obvious characteristic of flowers of the mallow family?

(19) How many bones are there in a human backbone?

(20) What are the names of the drugs used in the treatment of malaria?

(21) Why are coloured bottles often used for storing chemicals?

Questions concerned with local lore (see Chapter VIII, page 171) are admirable for a 'quiz' of this kind.

Field excursions

A class excursion must be planned with care, and for a specific purpose. Pupils should be given some idea of what they are likely to see, and of the points of scientific interest for which they should look. The excursion should be followed by some class activity such as the writing of descriptive essays; the making of scrap-books with newspaper cuttings, pictures, or material produced by the pupils themselves; the production of an article for the school magazine; model-making; and so on.

Interesting information can be gained if a class is taken at different seasons of the year to the same local area to look for flora and fauna. Points to be noted may include the ways in which living things adapt themselves to dry and wet seasons, the different times of flowering and fruiting of plants and of breeding of birds, and the presence or absence of various species of animal life, especially butterflies. One of the most interesting subjects of study is the seasonal variation in the bird population. It is not difficult to find out, for instance, that weaver birds inhabit their colonies for part of the year only; that white egrets and kites, which are so readily identified, are much more numerous at some times of the year than at others. The notes of various birds with distinctive songs and calls may be memorized. Information on many matters of this kind may often be obtained from members of local natural history societies, who are often pleased to invite pupils to co-operate with them in keeping records of the habits of local creatures. Such enthusiasts are usually willing to help teachers and pupils to identify snakes and other reptiles, rodents, birds, etc.

Suitable organization is essential for any investigations, especially in natural history. For example, groups should be small, with not more than three pupils and a leader in each, and should work far enough apart to avoid disturbance of the wild life, or each other! Every pupil should have a definite task, the leader being responsible for collecting all the information together at the end. Notes should be entered, immediately the particular observation has been made, under definite headings. These might be, for instance:—

(*a*) In the case of *flowers*:
- (i) Place where found, and date
- (ii) Size of plant
- (iii) Kind of ground (farm, forest, rocky, sandy, marsh, etc.)
- (iv) Flower:
  - Type (solitary, in heads, etc.)
  - Size
  - Colour
  - Shape
  - Number of petals
  - Number of sepals
  - etc.
- (v) Leaves:
  - Type (simple, opposite, etc.)
  - Shape, kind of edge
  - Stalk
  - etc.
- (vi) Fruit:
  - Type
  - Shape
  - Colour
- (vii) Root:
  - etc.

(*b*) In the case of *birds*:
- (i) Place where found, and date
- (ii) Size
- (iii) Habitat
- (iv) Colours of main features
- (v) Shape of beak, feet, tail, wings
- (vi) Any special features
- (vii) Flight (direct, swerving, dipping, gliding, swooping, etc.)
- (viii) Gait (walk, hop, run, etc.)
- (ix) Call
- (x) Food
- (xi) Nest (material, construction, place where found)
- (xii) Eggs (number, size, colour, etc.)

The numbers and details of headings and sub-headings for any particular subject will depend, of course, on the pupils' age, experience and knowledge.

The resources of the community

In most communities there are individuals who possess special knowledge, for example, of local flora and fauna, or the care of domesticated animals. They can be invited to put their knowledge at the service of the school, either by answering questions by a teacher and his class, or by permitting a class to visit the buildings or farms where they exercise their particular skill or crafts. The teacher may be warned that to invite people inexperienced in the art of teaching to deliver a formal lecture to children often results in failure. For that reason it is better to invite them to answer questions, so that the teacher may keep the subject-matter within the range of interest and knowledge of his class.

In some areas the government may have set up experimental farms. The interest and help of the agricultural officers is usually readily available to the teacher. If any economic product, whether agricultural or mineral, is obtained from the area in which a school is situated, then contact should be made between the school and those in charge of the industry. Permission can then be obtained for classes to visit the scene of operations. The information obtained usually provides confirmation of more formal scientific knowledge gained in school. The flat, metal evaporating-pans of crude salt works illustrate the fact that evaporation takes place more rapidly when a large surface is exposed. Methods of producing a forced draught are used in places where local brass workers exercise their craft. Pupils may note the way in which air is kept away from heaps of wood which are being turned into charcoal. To these and many other examples attention may be drawn with great profit. The pupil gains a respect for the practical knowledge of his countrymen, and the local craftsmen realize that education is not concerned solely with matters remote from everyday life.

School exhibitions and 'Science fairs'

It is customary for a school, at least once a year, to invite interested people to a display of its various activities. The science department can play a considerable part in such a demonstration. It has apparatus which can be set up, experiments to be performed, and a 'museum' to display. Because the background of all scientific work is practical, it can make an appeal to visitors which more academic activities may fail to provide. Pupils who help to organize such an exhibition themselves get a better understanding of the purpose of experiments and the methods used, all the more effectively because unconscious of the fact. The astute science teacher knows this and welcomes the occasion for that reason.

The range of experiments suitable for display and performance on such an occasion is wide, and no attempt can be made to list them all.

The science teacher should use the opportunity not merely to impress but to instruct. One and the same experiment can be presented in different ways. For example, a row of capillary tubes of different sizes, held vertically in a coloured liquid, shows the liquid rising to different levels. If the title given to such an experiment is simply 'capillarity' the visitor looks, and passes on no wiser. Pupils who have not as yet met the subject in class will likewise be little the wiser. But if an explanatory card, with title and explanation (see Figure 35), is put near the experiment, an almost meaningless piece of apparatus at once becomes an illustration of a phenomenon with which everyone is acquainted.

WATER RISES IN SMALL TUBES (CAPILLARITY)

The tiny particles of the glass attract the tiny particles of the water and pull them up the tube. When the tube is small the column of water inside it is lighter, and so the water is pulled farther up. Plants and trees are provided with bundles of extremely small tubes which lead all the way from the roots to the leaves. Water travels up these tubes in much the same way. This is one explanation of how water gets from the earth to the leaves of even very tall trees.

FIGURE 35.—A typical display card (for apparatus in a school exhibition)

Selected pupils should be in charge of the various experiments, to work or explain them. In the excitement of exhibition day pupils' explanations are sometimes rather incoherent. So at least one lesson may well give place to a conference before the exhibition. The pupils can discuss the wording of the explanatory card to be placed by the side of each experiment, and thus get practice in reviewing the experiments critically. In thinking out ways and means of setting out the problem so that its purpose is clear, organizing the experiment so that the answer is unmistakable, and in thinking out phrases which will succeed in making it clear to others, pupils will themselves understand the purport of the experiment all the better. Even the mechanical act of printing the agreed descriptions on cards will help impress the facts on their memories.

'Museum' exhibits, charts and diagrams are already at hand for display. Models, in relief, of the human eye, ear, head and abdomen always arouse interest. The following list suggests a few of the many other exhibits and experiments suitable for the occasion.

BIOLOGICAL

Nutrition of plants, illustrating the effect of the lack of various elements
Transpiration of plants
Growing point of radicle
Respiration of plants
Examples of tropisms
Oxygen from pond weed in sunlight
Germination of seeds
Experiments showing the physical properties of various soils
Experiments showing osmosis
Starch printing with leaves

CHEMICAL

Distillation
Boiling under reduced pressure
The preparation of nitric acid
The electrolysis of water
Chemical fountains
The preparation of hydrogen
The formation of crystals

PHYSICAL

Working models of pumps
Experiments using a vacuum pump
Mechanical devices: pulleys
- wheel and axle
- levers
- gears

Pendulums (simple, to show that only length matters)
Experiments with light rays: reflection
- refraction, etc.

Reflections in large concave and convex mirrors
Images in plane mirrors at an angle

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SERVICES

Small convex and concave lenses (showing the same size of object under each)
Pin-hole camera
Models of solar system — Star charts
Model Galilean telescope directed to distant object
Experiments in colour: spectrum
colour mixing
Newton's disc
Model telegraph — Electro-plating
Electro-magnets — Electric motors
Magnetic fields around magnets

Science clubs

However well thought out a school syllabus may be, and however wide the range of interests catered for, each individual is likely to have his own special enthusiasms. This is true of teachers as well as pupils. When a few like-minded individuals get together a club may be founded. Numbers are of less importance than the sharing of a common interest.

School clubs should have a teacher as a patron, his task being to advise and encourage, to approach the headmaster to ask for any special facilities, and to supervise correspondence and invitations to visitors. The students should elect from among their own number a chairman, secretary, treasurer and committee. The objects of the club should be defined, eligibility for membership agreed upon, the number and time of meetings fixed, and the questions of finance and subscriptions decided.

The less the patron is needed to help in organizing the club the better. It is for the members themselves to suggest a programme, to arrange demonstrations and exhibitions, and to construct models. Visits to objects and places of interest may be planned, a film of particular scientific interest may be shown and discussed from time to time, and outside speakers may be invited to give occasional talks.

The interests of the club may be general, with a wide range of activities, or more limited as in a photographic club, a mathematical society, a model makers' club, and so on.

One profitable activity in which a club may engage is in organizing a 'nature trail'. A route is selected along a path or track near by, and a large-scale map is drawn. Upon the map is marked the position of various items of interest along the route: plants, trees, birds' nests, ant (termite) hills, wasps' nests, etc., and further items are added as they are discovered. When possible the actual objects themselves are identified by special permanent (but not too conspicuous) markers. Each object is visited at regular intervals throughout the year and its condition noted. In this way seasonal changes become evident, and can be summarized in reports drawn up by members, or by entry on the large-scale map for exhibition on a notice board.

The types of subject appropriate for talks, illustrated wherever possible by pictures, diagrams, charts, specimens, models, etc., are suggested in the following list. They are appropriate to a club with general interests.

Colour changes in chemistry
My model telephone
Our water supply
How big is a drop?
The life of a famous scientist
How a motor-car makes and uses electricity
Jobs open to scientists
The simplest wireless (radio) set
How to find a certain star
Cameras
The structure of an atom
Prehistoric animals and birds
Colour photography
A rare local plant
Recognizing bird calls
Fireflies and glow worms

Talks given by members should rarely exceed fifteen minutes. Several short papers are far better than a long one. It must be remembered that 'talks' do not consist entirely of talking, but should be accompanied by demonstrations of experiments and display of relevant material.

In schools where laboratory accommodation and facilities are limited, much of the effective practical and experimental work for pupils may have to be arranged outside normal school hours. In such circumstances the teacher will find that a science club is one of the best means of organizing the work and stimulating interest.

The science library

If a school has a room set apart as a library and reading room with a responsible person in charge, then a science library can be established as a section of the general library. Failing this, it is best for a science library to be in the care of the science teacher, and for the books to be kept in a science room. It should be possible for pupils to see easily what books are available—an important point often overlooked when books are kept in cupboards with wood-panelled doors, or in rooms not normally open to pupils.

Books should be available for reference, or for borrowing, without undue difficulty or delay, so that even a slight interest may be satisfied before it evaporates.

One advantage of having the books under the immediate control of the science master is that he can observe to what extent pupils are attracted to additional reading, and note any particular fields of interest.

Occasionally, during a lesson, in response to a question (even though the teacher may know the answer), he can himself search for the answer in the books available, and in so doing, give a practical demonstration of how to look up information in a library, and give guidance on the most suitable kinds of book in which to seek information about the various fields of science.

Books for a science library can be divided into several categories, each serving a particular purpose. The titles given below indicate the type of book which is appropriate to each category.

(*a*) '*Inspirational*' *books:—*

The wonder book of trains
                    of engines
                    of invention and discovery
Man against microbes
Wonders of pond life
The harvest of the sea
Reptiles, large and small

The romance of chemistry
Great ends from small beginnings
The triumph of man over matter;—and also
biographies of Pasteur, Fabre, the Curies, Copernicus, etc.

The purpose of books of this category is to arouse interest, to show the innumerable ways in which science influences our lives, and the response that great men and women have made to the challenge of the unknown.

(*b*) '*Background*' *books:*—
Electricity in the home
The human machine
The work of a forestry officer
How new plants are bred
The story of coal
The story of penicillin
Radar
How life came on the earth

There are vast numbers of books of this type now available, and they are of special importance and value for pupils whose home life provides little general and 'background' knowledge.

(*c*) *Reference books:*—
An encyclopaedia
A dictionary of science
A history of science
A book of moths, butterflies, insects
Local flora
Economic plants
Common birds
Star atlas and guide
Almanacks
Tables of physical constants

This section should also include some text-books of about the same standard of difficulty as the ones in current use by the classes, and some slightly more advanced ones. The former are often of great help to pupils, who find that a different presentation of a subject in another book helps them to understand what their own text-books fail to make clear. The latter are of use to those who wish for more extensive or detailed information about some topic.

Desultory reading of science books is not to be discouraged, but a teacher cannot be satisfied until his pupils use the library in search of definite material.

(*d*) *Science magazines:* It has been suggested (Chapter VII, page 133) that magazines should be available for pupils to read during spare minutes at the end of laboratory periods. They are a constant reminder that science is a growing body of knowledge which finds ever new applications in the world around us. The current issues of appropriate magazines should be kept on view in the library.

The choice of books—Every science teacher has to make a selection of books for reference, for his own use, for his pupils' formal studies, and for the science library. A list of books is given in Appendix F, page 341, to indicate the extent and variety of literature available for the various purposes, and as a guide to the choice of a well balanced collection.

Two points must be stressed. (1) In schools where the pupils have done little or no science during their primary courses, they should be encouraged to read as many simple science books as possible—and to do many of the experiments recommended in them. This is essential if the foundations of the secondary course are to be sure and firm. For this reason the book list includes some elementary volumes. (2) Teachers should keep a look-out for books specially written or adapted for their own country or area. The number of such books increases with the growth and spread of knowledge, as can be seen from such titles as: 'Some tropical plants and their uses', 'Wild flowers of Kenya', 'Tropical soil science', 'Indian hill birds', 'The African and his livestock', 'Health in tropical schools', 'Animals in West Africa', etc.

CHAPTER XI

The Practical Teacher

Improvising equipment

Let no one suppose that it is impossible to teach General Science without most of the apparatus and equipment listed in Appendix E, page 307. Stringent economies may have to be made; the delivery of apparatus and chemicals may be long delayed, or apparatus may be temporarily unobtainable.

The poor teacher complains, blames lack of equipment for the dullness of his lessons, and allows his pupils to revert to the dull monotony of note-taking and passive learning of the text-book. The good teacher, however, finds in the same circumstances a challenge to his ingenuity. With an alert mind he adapts his lessons to the materials available. There is always the great 'out of doors'; the winds and the clouds, the stars, the changing seasons. There are germinating seeds to be watched, flowers to be seen, methods of fertilization to be noticed; plants to be grown, and the structure and functions of their various parts to be studied. There are local insects, spiders, lizards and frogs, birds and fish which claim attention. Some may be kept in a vivarium or an aquarium. There are small animals to be reared, others to be dissected. The human body, that amazing laboratory, we always carry around with us, providing us with object lessons in mechanics, light and sound, chemistry, and biology.

Should there be no magnesium or phosphorus to exhibit vividly a particular example of oxidation, there are always available on the small scale nails and screws, and on the large scale massive iron objects. And though the oxidation of magnesium and phosphorus may be more swift and exciting, the oxidation of iron is vastly more important.

The list of substitutes for the commoner laboratory equipment is as long as the teacher is ingenious. With patience, simplified versions of more complicated apparatus can be made. In fa ct thesimpler the apparatus the better is the pupil able to appreciate the methods used and the facts to be illustrated. The refinements required in order to obtain very accurate results belong to apparatus more suited to the needs of advanced students. Such apparatus is often complex, and making the various corrections, which its proper use usually demands, can be a source of more confusion than help to the beginner. Some emergency, or simply the need for economy, can develop the ability to construct apparatus that would otherwise be bought. This gives practice in improvising original devices, and results in a class being confronted with equipment which may be crude, but of which the function is clear. Such contingencies, far from being a disaster, provide benefits of great value to both teacher and taught.

For a rain gauge there may be no cylindrical brass case, with a brass funnel and a measuring cylinder exactly graduated to suit the apparatus. Yet it may be noted that in at least one works for the extraction of salt from sea-water by evaporation, the night's rainfall is measured simply by noting the depth of water in an empty canned fruit tin left upright in an exposed place. No better apparatus exists for teaching what, precisely, is meant by a 'rainfall of one inch'.

Diagrams intended to show how certain devices work are often difficult to follow. It is far better if the pupil can handle the device itself, and take it to pieces. It would be unreasonable in most instances to treat new instruments in this way, but old, discarded pieces of apparatus can readily be used for the purpose. Such pieces of apparatus, thrown out because no longer serviceable, can often be found in junk heaps, in garages, in cycle-repair shops, in radio-repair shops, in electric supply stations and in electrical contractors' sheds. All sorts of useful oddments are thrown away by builders, and by maintenance men working on engineering and electrical projects. All these can be 'dissected to destruction', or used lavishly. A friendly contractor can save a science laboratory a great deal of money at no cost to himself. To make such acquaintances is one of the tasks that lie within the science teacher's proper duty; to acquaint his class with the source of his booty, is the teacher's reasonable return to the donor.

Suggestions for the construction of simple apparatus, equipment and models, may often be found in good text-books and magazines. A school club for model-making can render the science department great service.

The following is a collection of suggestions for equipment which can be substituted for items included in Appendix E, part I. Instructions are given for making some pieces of apparatus, but the list is by no means exhaustive, and teachers should be continually on the look out for useful additions.

NOTES ON SOME POSSIBLE IMPROVISATIONS

Accumulators, lead—Car batteries are of this type. Old accumulators can be obtained from garages. They can be cut through with a hack-saw to show the construction of the plates, the wooden separators, etc. Notes on the charging of batteries are given in Chapter IX, page 194, and details of the solutions in this chapter, pages 265–6.

Aluminium sheet—Off-cuts from roofing sheets can often be found among building contractors' junk.

Ammeters—These form part of the equipment found on the instrument panel of any car. They are often obtainable from old cars at a garage.

Armatures—The self-starter of a car is an electric motor, and an old one is often obtainable at a garage. The motor should be partly dismantled to show the armature (the part that turns round) with its commutator and brushes.

Asbestos sheets—Off-cuts of asbestos sheeting can usually be found in builders' junk. Pieces may be cut into convenient square or rectangular shapes with a hack-saw.

Beakers—Empty jam-jars are a useful substitute, if the jars and contents are not to be heated. Cigarette or canned fruit tins can be used for heating liquids.

Botanical specimens—These can be pressed and dried between sheets of newspaper. A large number of specimens can be pressed at one time if a sheet of stiff corrugated paper, such as is used for packing, is placed between every three or four specimens.

Bottles: *Narrow neck*, for liquids—Various kinds and sizes, which, when originally purchased from drug and haberdashery stores, contained medicines, etc., may be used. Those with plastic screw-tops are to be preferred. The paper, or rubber, washer inside the screw-top must be removed and washed, or replaced.

Wide-neck, for solids—1 lb. and 2 lb. empty jam-jars can be used.

Sweets are frequently sold in screw-top wide-neck bottles, and these are very suitable for solid chemicals. Very large screw-top wide-neck bottles can be used for storing solid chemicals, i.e. as the stock bottles from which smaller containers are refilled periodically.

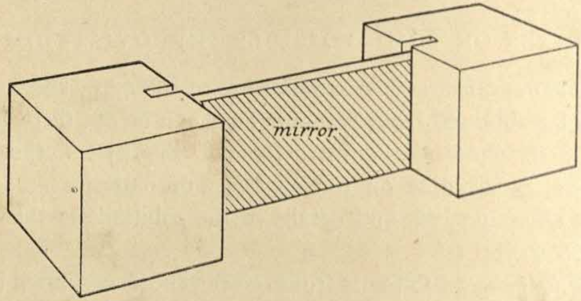

FIGURE 36.—Simple mirror (or lens) holders

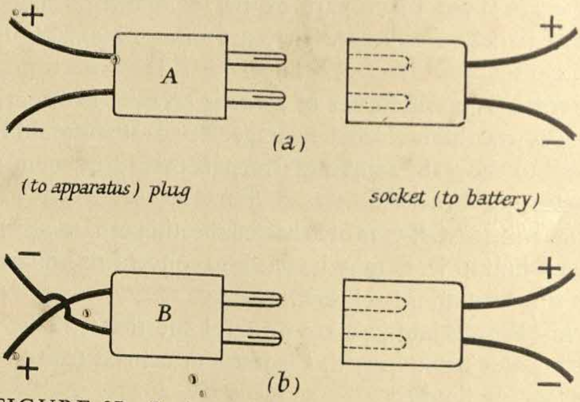

FIGURE 37.—Socket and plug as substitute for commutator
A—first side of plug facing user
B—plug turned over so that opposite side faces user

Calorimeters: Large—Empty 2-lb. canned fruit tins can be used. *Small*—Empty 1 lb. canned fruit tins, or cigarette or tobacco tins, can be used. If quantitative measurements are being made, it should be remembered that 'tin' is mainly iron covered with a very thin layer of tin. The specific heat of the 'tin' can be taken as 0·11 calories per gram.

Clips, spring (for rectangular mirrors)—A wooden rectangular block, with a saw-cut vertically down one face, will usually hold plane mirrors satisfactorily. Two such blocks are better, and can also be used for spherical mirrors and lenses (see Figure 36). Clothes pegs of the spring type also make satisfactory mirror and lens holders.

Cloths, polishing—Any clean, soft rags are suitable for most purposes, but expensive lenses need special, soft cleaners.

Collecting boxes, glass-topped—A rectangle of ordinary window, or picture, glass can be cut so that it is somewhat smaller than the lid of a rectangular cardboard box. A rectangular hole, smaller than the piece of glass, is made in the lid. The glass is put over the hole and bound in place with strips of adhesive material. Transparent adhesive strips are the most suitable. The making of such boxes provides a useful activity for a handwork class.

Vasculum—A large shallow (e.g. biscuit) tin, though not as conveniently shaped as the botanist's vasculum, will serve the purpose. The lid must be a reasonably good fit.

Commutators (for reversing the direction of a current)—These switches are useful, but expensive and rarely essential. A two-pin plug and socket obtainable from a radio supply shop will serve. A reversal of the positions of the pins in the socket, as from (*a*) to (*b*) in Figure 37, means that the direction of the current through the apparatus is reversed. In countries where Edison screw fittings are not available, a bayonet adaptor and lamp-socket can be used in the same way. Commutators involving the use of mercury in small 'cups' are seldom necessary and cannot be recommended.

Condensers, electric—Fixed and variable types can often be found among the junk in a wireless repair shop.

Cork presser—(See '*Tricks of the Trade*', page 251.)

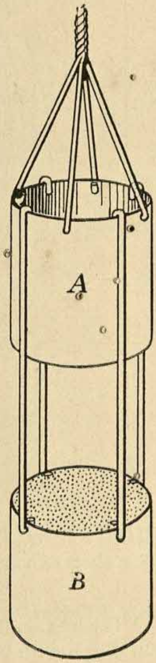

FIGURE 38.—Substitute for 'bucket and cylinder' (in a demonstration of Archimedes' principle), see page 232:

A—empty tin (small)
B—tin of equal size filled to brim with wax

Cylinder and bucket—Two small tins of equal size are required to make an effective substitute for the usual apparatus. One is filled with molten paraffin wax, which is allowed to set.[1] They are then attached to one another as shown, and may be suspended in water from a balance in the usual way (see Figure 38).

Dip circle—The angle of dip in the tropics is usually very small. Unless a sensitive and expensive apparatus is purchased and corrections for the various errors applied, the values obtained are very approximate, so that the experiment is not impressive and may well be omitted at this stage.

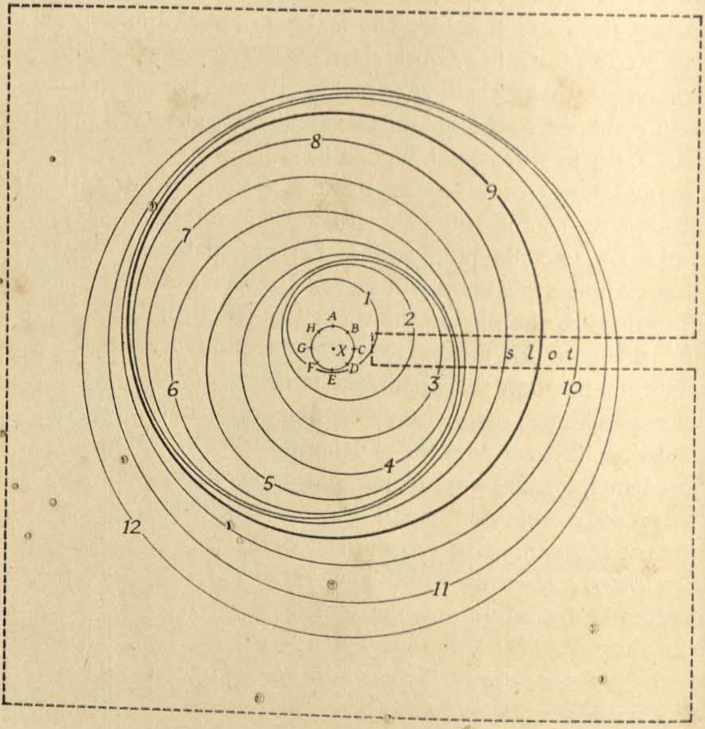

FIGURE 39.—The construction of Crova's disc. (The rotating disc is covered by a sheet of cardboard with a slot cut out as shown. One circle, e.g. (9), may be coloured)

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[1] The wax used must be denser than water, or some small clean stones may be put into the tin before the wax is added.

Disc, Crova's (for demonstrating longitudinal waves)—In the middle of a large piece of white drawing paper, a circle (0) with centre X, and radius ¼-inch is drawn, as in Figure 39. The circumference is divided into 8 equal parts at the points A, B, C, D, E, F, G, H. With centre A, a circle (1) is drawn, so that it lies just outside (0). With centre B, a circle (2) is drawn, so that it lies just outside (1). With centre C, a circle (3) is drawn, so that it lies just outside (2); and so on. After circle (8), with centre H, has been drawn, circle (9), with centre A, is put in, and the process is continued until the paper is full. The paper is then pasted on to a piece of stiff cardboard, and cut into a disc with centre X. The disc is rotated about X. The circles should be drawn with thick lines, to make them easily visible from a distance. One circle, e.g. (9), may be coloured red. A slot, about ¼-inch wide, is cut in a large piece of cardboard, which covers the disc, as shown. When the disc rotates, only the lines immediately behind the slot can be seen.

Dishes—Enamel and glass dishes suitable for much of the biological work in the course can usually be obtained locally.

Dissecting needles—A large pin is bent twice, at right-angles, and put into a slit in the end of a pencil or penholder. The pin is bound in place with cotton or fine wire (see Figure 40).

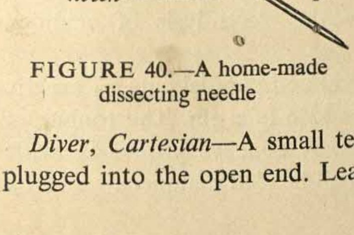

FIGURE 40.—A home-made dissecting needle

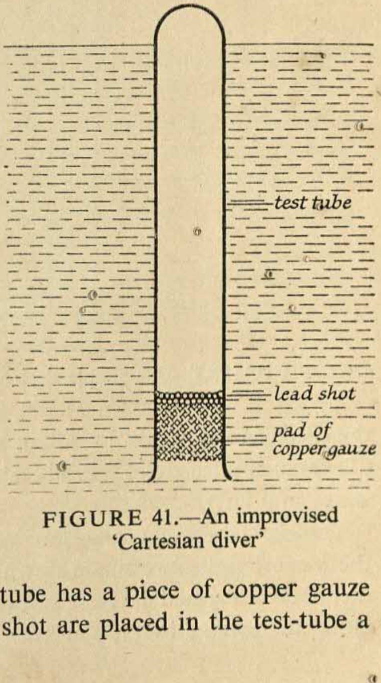

FIGURE 41.—An improvised 'Cartesian diver'

Diver, Cartesian—A small test-tube has a piece of copper gauze plugged into the open end. Lead shot are placed in the test-tube a few at a time, until it will almost sink when placed in an inverted position in a glass cylinder of water (see Figure 41).

Electrodes, platinum—A convenient type can be made by inserting a piece of platinum wire, 1 inch in length, in the end of a glass tube, which is then sealed by softening in a flame. The tube is then bent as shown in Figure 42. Contact between the copper lead-in wire and the electrode is made by filling the U of the tube with mercury. (Two such electrodes readily show the electrolysis of acidified water in a jar.)

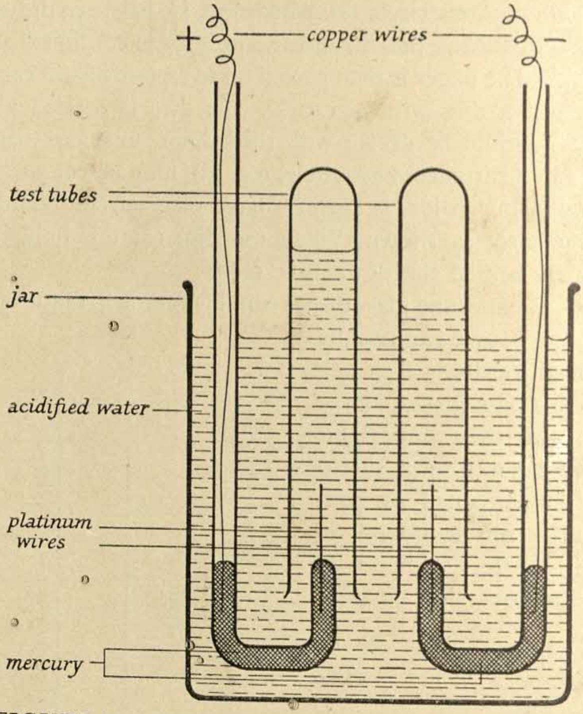

FIGURE 42.—Simple electrodes for the electrolysis of water

'*Eureka*' (*overflow*) *can*—Two vertical and parallel cuts, of exactly the same length, are made down the side of a tin. The tongue of metal thus formed is bent outwards. A concave groove is made along the tongue by tapping with a ball-headed hammer or an iron rod (see Figure 43). The object, the volume of which is to be found, is inserted slowly, so that all the displaced liquid flows down the groove into the receiving vessel.

Filter paper—There are times when it is useful to remember that a sheet of white blotting paper can be used in place of filter paper.

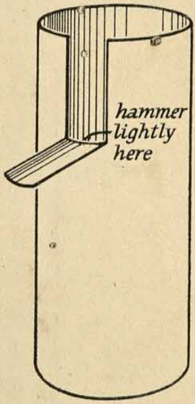

FIGURE 43.—An overflow ('Eureka') can

Fuse holders, porcelain—These can usually be found in the junk heap of a contractor for electrical installations.

Gauge, pressure (*Bourdon*)—The commonest instrument for measuring pressure is the Bourdon gauge. The oil-pressure gauge on the instrument panel of a car is of this type; so are the gauges attached to pressure cookers, steam sterilizers, autoclaves, etc. Most of these gauges register the difference between atmospheric pressure and the pressure to be determined. That is, an actual pressure of 15 lb. per sq. inch shows zero on the scale, while an actual pressure of 25 lb. per sq. inch shows only 10 lb. per sq. inch on the scale. If actual pressures are to be shown on the instrument the needle must be removed and replaced so that the instrument shows about 15 lb. per sq. inch on the scale under ordinary conditions. The gauges, even when salvaged from old and abandoned cars, are usually in satisfactory working order.

It is easy to make a model to demonstrate the principle on which the gauge works. Two pieces of paper, one stiff, about 8 inches × 1 inch, the other softer (e.g. note-paper) about $8\frac{1}{4} \times 1\frac{1}{2}$ inches are placed together. A $\frac{1}{4}$-inch margin of the larger piece is turned over along the sides and one end of the smaller piece. These edges are then stuck down by the minimum amount of gum. While still wet the two layers are rolled into a tight roll, held in position with a rubber band, and allowed to dry. The paper remains curled up when the rubber band is removed. If the coil is unrolled a little and air is blown into the space between the strips, the coil will tend to unroll further (see Figure 44). The greater the pressure of air, the more it unrolls. A Bourdon gauge contains a hollow coil, which is connected

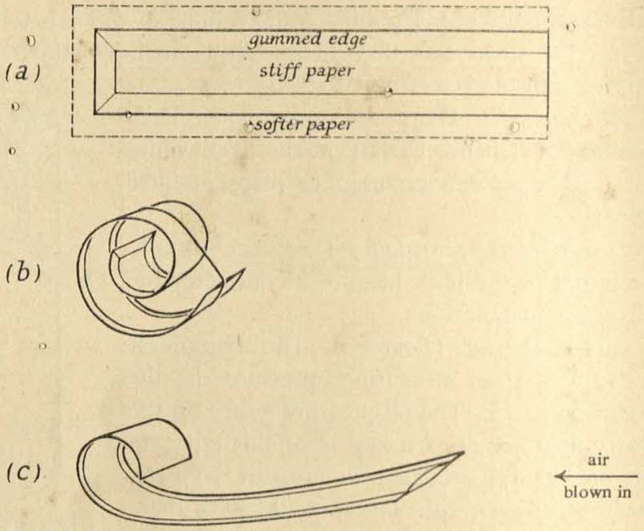

FIGURE 44.—To show the principle of the Bourdon gauge

(*a*) Strip of soft paper gummed round stiffer strip
(*b*) Strips rolled and held in position by rubber ring
(*c*) Increase of pressure unrolls the coil

to the source of pressure, whether liquid or gas. The greater the pressure the more the coil unrolls. A needle attached to the coil moves over a dial and records the amount of unrolling and thus of the increase in pressure.

Gauge, rain—If local records show that the greatest rainfall in any 24 hours amounted to 8 inches, for example, then the size of the bottle should be somewhat larger than would hold this amount of rain. Otherwise, if the bottle is too small, and the rainfall is about to set up a new record, the bottle will overflow and the apparatus will fail to measure the exceptional amount.

Any tin or jar, of uniform cross-section and diameter, preferably not less than 6 inches, can be left in the open and used as a rain gauge. The depth of water in the tin is measured by a 'dip-stick', i.e. a graduated metal or wooden rod or bar. (The zero of the scale *must* coincide with the end of the measuring rod—which it does *not* do in the case of ordinary class-room rulers.)

A gauge intended to yield more accurate results is shown in

Figure 45. The minimum diameter for the mouth of the funnel is 6 inches. The approximate value for a heavy rainfall may be obtained by a dip-stick or the careful use of a ruler outside the jar—*if* the internal diameter of the jar is the same as that of the mouth of the funnel. But the diameters are unlikely to be the same, and in any case there must be a better method of measurement. The water can be poured into a narrow glass cylinder and its depth measured. If H represents the rainfall, L the depth of the water in the cylinder, *f* the diameter of the funnel and *c* that of the cylinder, then the volume:

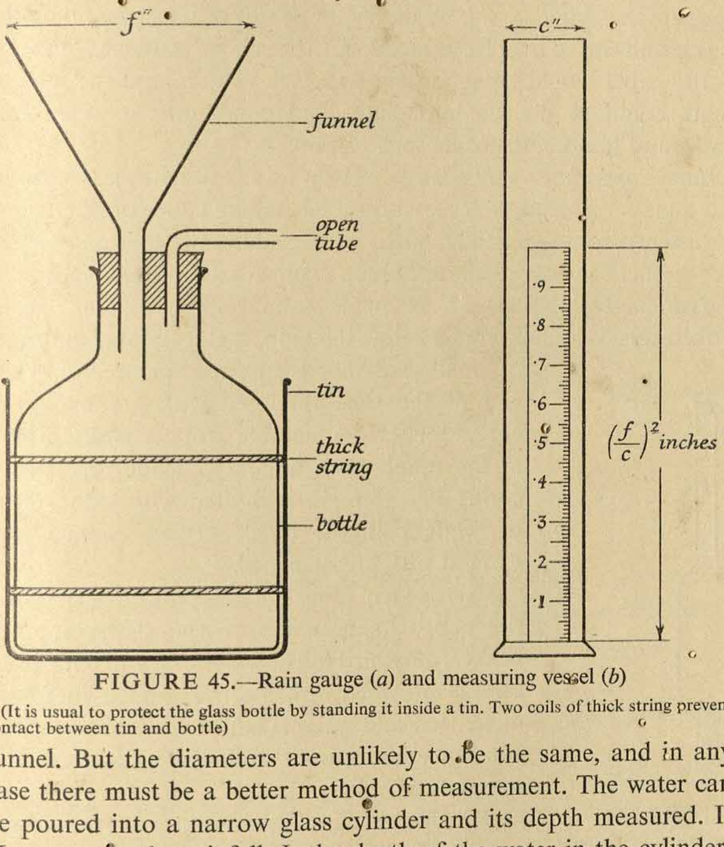

FIGURE 45.—Rain gauge (*a*) and measuring vessel (*b*)

(It is usual to protect the glass bottle by standing it inside a tin. Two coils of thick string prevent contact between tin and bottle)

$$V = H\pi\frac{f^2}{4} = \frac{L\pi c^2}{4}$$

$$\therefore H = L.\frac{c^2}{f^2}$$

Thus, if $f = 6$ inches and $c = 2$ inches, $\frac{c^2}{f^2} = \frac{1}{9}$, so that 9 inches of water in the cylinder represent a rainfall of 1 inch.

To avoid calculation after every measurement, it is usual to graduate the cylinder, e.g. by marks on a strip of paper gummed to its side and waxed over for protection. In the above instance, 9 inches on the paper would be equivalent to 1 inch of rain, and the 9-inch length could be divided into tenths and hundredths to represent tenths and hundredths of an inch of rain.

Hare's apparatus—This can be set up using straight glass tubing and a glass or metal T-piece, with rubber-tubing connexions. It can be fastened to a wooden stand by brass saddles, or the long tubes may be held in two separate burette clamps fixed on one stand.

Hydrometers—These can be made from broken pipettes. The broken tube is sealed off just below the bulb, and a suitable amount of small lead shot is inserted (Figure 46). The end of the tube is closed with a rubber, or cork, stopper. (A suitable stopper is often left in the borer when a hole is made through a cork.) The stem is calibrated with thin rings of white paint or quick drying enamel, or marked with grease pencil.

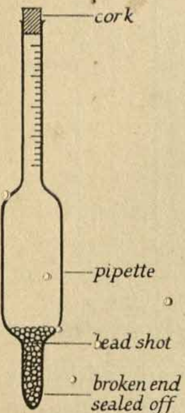

FIGURE 46.—A hydrometer (made from a broken pipette)

Hygrometer: *Dew-point apparatus*—To find the approximate value of the dew-point, a beaker, one-third full of water at room temperature, is provided with a stirrer and a thermometer. Ice-cold water is added very slowly, with constant stirring, until a mist begins to form on the outside of the beaker. The temperature at which the mist first appears is the dew-point.

Inclined plane—An adjustable plane can be made by a handwork class. Two pieces of wood, about 2 feet × 4 inches, are hinged together at one end, as shown in Figure 47. The lower one has a slot cut deeply and centrally along its length. The angle between the lower piece, which rests horizontally, and the other plane, is adjusted by using any wedge, block, or other device to hand. The pulley and roller are made from 'Meccano' parts.[1] Two wheels are sufficient, but more can be added to give extra weight. The pan for weights is the lid of a cigarette or tobacco tin.

Insulators—Various types can be picked up among junk in a wireless repair shop. Larger ones can be found in an electric power station.

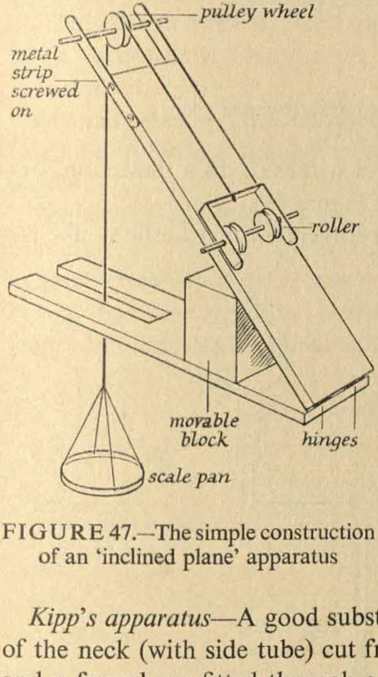

FIGURE 47.—The simple construction of an 'inclined plane' apparatus

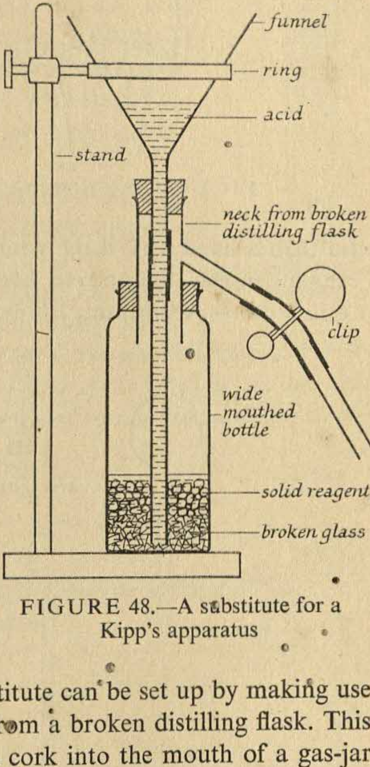

FIGURE 48.—A substitute for a Kipp's apparatus

Kipp's apparatus—A good substitute can be set up by making use of the neck (with side tube) cut from a broken distilling flask. This and a funnel are fitted through a cork into the mouth of a gas-jar or wide-necked bottle, which contains pieces of broken glass to a depth of about an inch (see Figure 48). The stem of the funnel is extended to reach the bottom of the bottle by means of a glass tube with rubber connexion. This apparatus is convenient for generating hydrogen, carbon dioxide, hydrogen sulphide, etc.

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[1] Toy constructional sets often contain parts which are very useful in making apparatus. 'Meccano' is one such toy, familiar to all English boys.

Lenses, watchmaker's—These are rather difficult for the unpractised to hold easily between cheek and eyebrow. But attached to an empty spectacle frame, in the place of one lens, they are far more useful than a hand lens, if the wearer wishes to do a dissection, or to examine insects, flowers, etc. (see Figure 49).

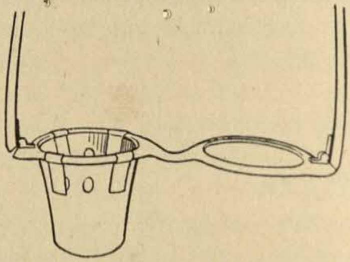

FIGURE 49.—How to hold a watchmaker's lens

Leslie's cube—A substitute for experiments with a Leslie's cube is arranged by placing an electric lamp midway between the bulbs A and B of a differential thermoscope. The bulbs can be coated with aluminium paint, dead black, white paint, etc., in turn, and the

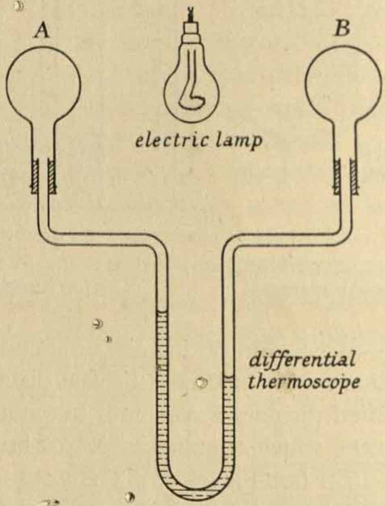

FIGURE 50.—An apparatus for use in place of 'Leslie's cube'

comparative rates at which the bulbs so surfaced absorb heat can be recorded (see Figure 50).

Magnets, electro-—A bundle of about 12 ordinary nails, half pointing one way, half the other, is wound round with about 20 yards of D.C.C.[1] copper wire, S.W.G.[2] 32 (see Figure 51).

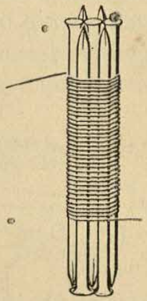

FIGURE 51.—A very simple electro-magnet

Magnetometer—Two half-metre scales are placed end to end in a straight line, with zero ends touching. A magnetic compass is arranged so that the centre lies over the junction. The more sensitive the compass, the more efficient is the apparatus.

Mirrors, plane—A discarded broken mirror can often be cut into a number of small rectangular mirrors.

Monochord (Sonometer)—An adequate apparatus may be fixed up along a laboratory bench or table, provided a pulley can be fixed by a clamp to the end of the bench. For comparing the notes given out by wires of the same length but differing thickness, the two wires are fastened end to end,

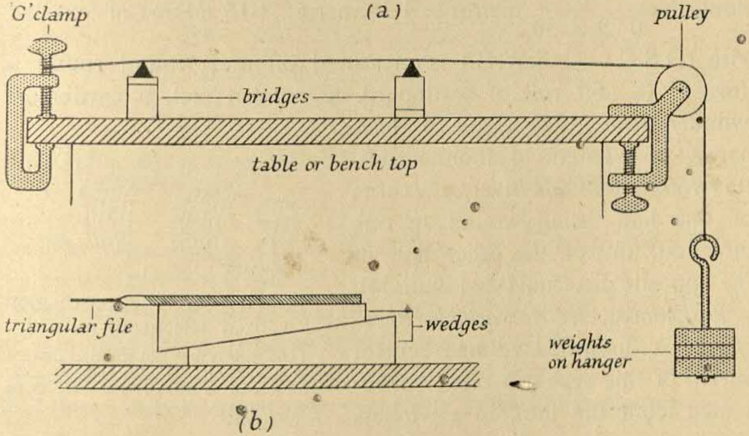

FIGURE 52.—A readily-arranged monochord (*a*). (*b*) shows an enlargement of a simply constructed adjustable bridge

and four bridges are used. A bridge of adjustable height can be made with two similar wooden wedges and a triangular file (see Figure 52).

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[1] Double cotton covered.

[2] Standard wire gauge.

Motors, electric—Discarded 'starter' motors, from a garage, are most useful for demonstrating the parts of an electric motor. Dynamos can be obtained from the same source.

Opisometers—These can be made from a 'Meccano' or other constructional set (see Figure 53).

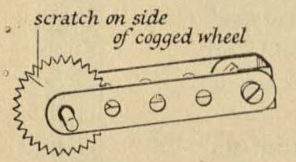

FIGURE 53.—An opisometer

Paper, drying for botanical specimens —See '*Botanical specimens*', page 229.

Rain gauge—See '*Gauge, rain*', page 236.

Resistance, electric, fixed—First, the required resistance (approximate), in ohms, must be decided upon. Then, from the table in Appendix J, page 363, may be found the length of copper wire needed to provide that resistance. For example, to make a resistance of 10 ohms, $10 \div 0{\cdot}29$ metres of 32 S.W.G. copper wire are needed. But because the resistance of 'eureka' wire is 30 times the resistance of copper wire of the same size, the length of 'eureka' wire required would be $\frac{10}{0{\cdot}29 \times 30}$ metres = 1·15 metres. 1·15 metres of 'eureka' wire (D.S.C.[1] 32 S.W.G.) is measured off and wound round a 'former' (a stiff roll of cardboard, a wooden reel, a cardboard cylinder from inside a roll of toilet paper, or a length of ebonite rod). It is wound non-inductively, the turns of one half being wound in one direction, and of the other half in the opposite direction (see Figure 54).

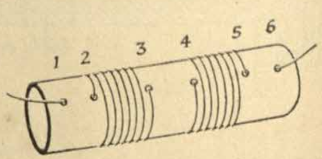

FIGURE 54.—The construction of a 'fixed' (electrical) resistance

(The wire is first put through holes 3 and 4, with equal lengths each side, and then wound as shown—the ends being fixed through holes 2, 1 and 5, 6 respectively)

Resistances, electric, variable (*Rheostats*)—A discarded volume control switch of this type can often be obtained from the junk in a wireless repair shop. It can be mounted on a piece of wood or ebonite. A resistance of this kind provides a useful control for electrolysis experiments.

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[1] Double silk covered.

Riders for balance beams—These can readily be made from aluminium wire.

Ring, iron—This can usually be made by a local blacksmith to any desired size. Alternatively, iron wire can be wound over pieces of string lying on the outside of a cylindrical 'former' (e.g. a tin or a cardboard cylinder). The string is tied so that it secures the turns of wire; the wire ring is slipped off the 'former', and wrapped with insulating tape to keep it in shape.

Rubber circles (e.g. for foot-operated bellows)—An unperished section is cut from a discarded football bladder.

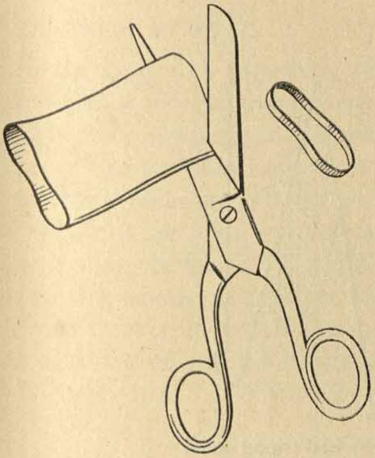

FIGURE 55.—Cutting rubber bands or rings

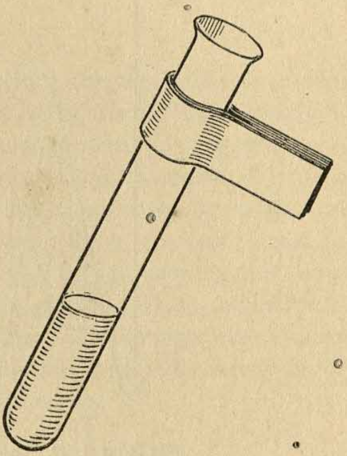

FIGURE 56.—The cheapest test-tube holder

Rubber rings—Rings can be sliced from the worn-out inner tube of a bicycle tyre (see Figure 55).

Scale-pans—The lids of cylindrical tins can be used. Instructions for arranging the suspending strings are given on page 259.

Test-tube holders—A piece of paper, folded into a strip of four to eight thicknesses, is an adequate substitute when wrapped round the tube (Figure 56).

Transformers—Discarded transformers can usually be obtained from the junk in a wireless repair shop. Suppliers of electrical apparatus sometimes have burnt-out transformers taken from old refrigerators, etc., and when partly dismantled these readily show their construction and, in particular, the way in which the iron core is made up of many thin sheets of the metal.

Tripods—Temporary contrivances can be made from large cylindrical tins which have both lid and base removed (see Figure 57).

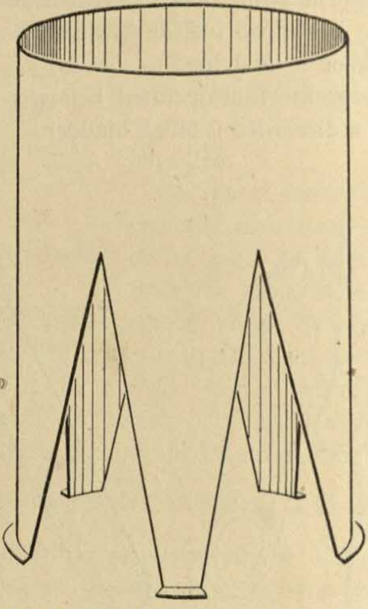

FIGURE 57.—An improvised tripod stand
(V-shaped pieces are cut out of the tin, and the feet are bent outwards)

Vernier model—A large-scale model, measuring perhaps 6 feet long, can be made in a handwork department. If the divisions are painted white they can more easily be seen by everybody in a large class.

Weight thermometers—Small density-bottles can be used in place of the usual type.

Wheatstone's bridge (*and potentiometer*)—A piece of well-seasoned board is essential. Permanent connexion between the terminals can be made with copper strip, but bare copper wire, S.W.G. 16, is quite adequate for most purposes. Bare 'contra' or 'eureka' wire, 26 to 32 S.W.G., will serve for the resistance wire (see Figure 58).

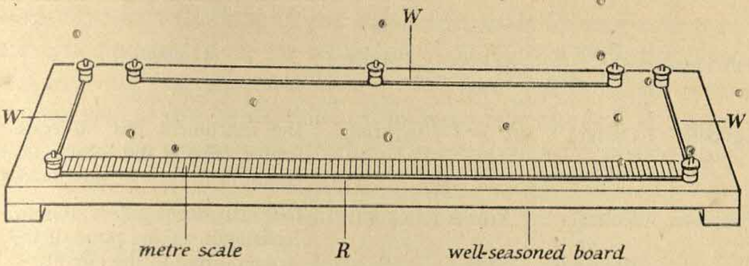

FIGURE 58.—A Wheatstone's bridge

R—Bare resistance wire (S.W.G. 26–32)
W—Bare copper wire (S.W.G. 16)

Laboratory technique

In the course of his career the science teacher discovers better, quicker or more convenient ways of doing things. His methods of laboratory maintenance, his handling of apparatus and experimental procedure gradually improve with practice and experience. The wise teacher is never too old to learn: he will remain constantly on the alert for 'useful tips', and will probably keep a book in which to make a note of any he finds. It is possible to pick up innumerable hints, suggestions, details of technique and procedure, of which the inexperienced teacher in particular is unaware. The following lists contain a selection of detailed information of this kind, which may be of assistance in the daily work of the laboratory.

'TRICKS OF THE TRADE'

(Notes on the care, maintenance and use of some common apparatus)

Ammeters and voltmeters—The moving-coil type is the common one in the school laboratory and on the instrument panel of an automobile, and is suitable for use on any direct current (D.C.) supply of electricity. But industrial and household supplies are usually of alternating current (A.C.), for the measurement of which ammeters must be of the moving-iron, or the hot-wire, type. The same applies to voltmeters.

Instruments with a zero-centred scale are often preferable to those graduated from zero upwards, because it is not always easy to decide upon the direction of the current in a circuit. This does not

Instrument	*What is measured*	*Symbol*	*Position*	*Assumption*
Ammeter	Current	C *or* I	In series	The instrument has no resistance, leaving the total resistance of the circuit unaltered.
Voltmeter	Voltage *or* Potential difference *or* Electromotive force	V *or* E *or* P.D. *or* E.M.F.	In parallel	The instrument offers infinite resistance, taking none of the total current in the circuit. (In general, the better the quality of the instrument, the more nearly are these assumptions correct.)

FIGURE 59.—The ammeter and the voltmeter in a circuit

matter in the case of a zero-centre instrument, and there is no need to change the terminal connexions. The table (Figure 59) gives further information.

Barometer tube and bell-jar (in the experiment to show that air pressure supports a column of mercury in a tube)—The tube is

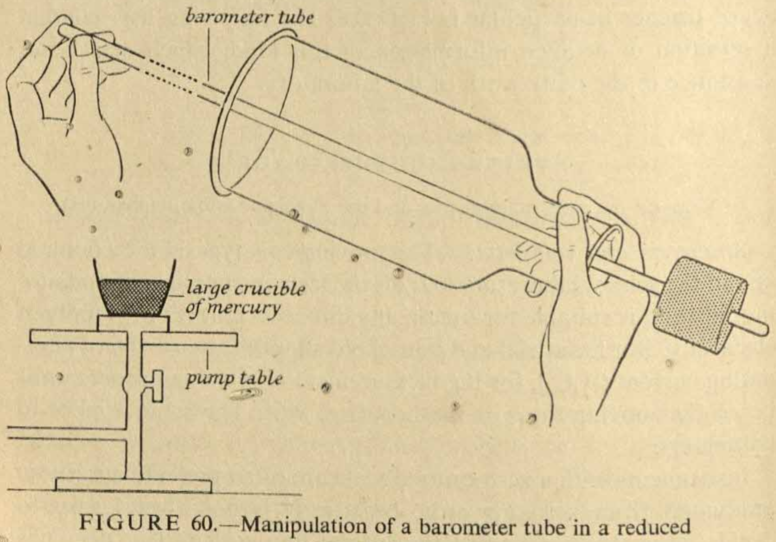

FIGURE 60.—Manipulation of a barometer tube in a reduced pressure experiment

passed through the hole in the stopper (it must fit well) and then through the neck of the jar, as shown in Figure 60. It is then filled with mercury (see '*Mercury*' below). The tube, and the neck of the jar, are held in one hand while it is inverted over mercury in a large crucible on the vacuum pump table. The jar is placed in position and the stopper gradually eased down the tube into the neck. (Vaseline or rubber lubricant helps in this operation, but patience is the greatest asset.)

Boyle's law apparatus—A glass J-tube can be replaced by two tubes, the shorter one sealed at one end, joined by rubber pressure-tubing. These can be set up in the appropriate J-shape in a stand. It is easier to get the right amount of air into the short tube when both tubes can at first be made to lean, independently, in any direction (see Figure 61).

Cleaning of glassware—100 g. of potassium dichromate are dissolved in a solution of 100 g. concentrated sulphuric acid in 1 litre of water. Glassware can be soaked in the solution, which may be used over and over again. CAUTION: great care should be taken to avoid getting this very corrosive solution on skin or clothes.

The teacher should use his knowledge of chemistry to remove stains of known origin. If dirty vessels have contained alkalis, or salts with alkaline reactions, then obviously the cleaning effect of a little dilute acid should first be tried; if the stain is due to potassium permanganate, then the effect of sodium sulphite solution, acidified with dilute sulphuric acid, should be tried; etc.

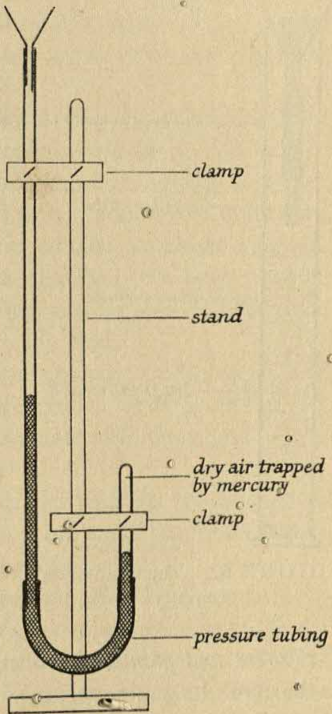

FIGURE 61.—Boyle's law apparatus

Alkalis slowly attack glass, and bottles which have contained caustic soda, etc., for a long time, will never recover their original transparency.

Cleaning of mercury—When mercury, flowing over a surface, begins to leave 'tails', it should be cleaned. It is allowed to drip into a tall cylinder containing nitric acid slightly more dilute than the usual bench reagent. If the mercury falls through the acid in a fine stream, as it does when made to pass through a capillary tube attached to the end of a funnel, so much the better (see Figure 62). The mercury is then shaken up with water in a strong bottle to wash it free from acid. Finally it is allowed to pass through a pin-hole made in the middle of a filter paper, which is folded in a funnel in the usual way. The last drops of mercury remaining in the funnel should be kept for the next occasion when mercury is cleaned. The mercury may be warmed in an air oven before the final filtering, if required particularly dry.

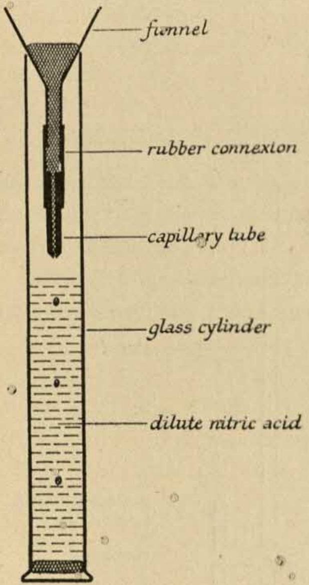

FIGURE 62.—The cleaning of mercury

Cleaning of paint brushes—After the removal of as much paint as possible, the brushes should be washed out immediately with warm water and soap.

Collections of biological material—These have little value unless they are kept in good condition, and the various kinds require different treatment.

Flowers and plants—A collection of dried specimens is called a herbarium. Its main purpose is to provide a supply of identified plants for general reference and to facilitate the naming of freshly collected specimens. Further, the teacher has always at hand a supply of material with which to illustrate the various kinds of flowers, leaves, fruit and roots. A specimen is not complete until all the parts of a plant are present. As flowers and fruits do not always appear at the same time, it may be necessary to collect specimens of a plant on more than one occasion.

Plants can be dried by pressing between sheets of newspaper. Special paper can be purchased for the purpose, but newspaper makes a satisfactory substitute if two or three sheets are put on each side of the specimen. A number of layers of specimens can be pressed at the same time. Drying is assisted by insertion of sheets of stiff corrugated paper between every few layers. The pressing can be carried out by putting the sheets, on a table, under a heavily weighted drawing board. But drying is quicker between two wire frames pressed together by spring fasteners, adjustable screw fasteners, or straps. For the first few days the specimens should be removed and placed between fresh dry paper every day, but as they become drier the changes need be made less frequently.

Specimens are less subject to the growth of mould if brushed over gently with a solution of ½ g. of mercuric chloride in 100 ml. of methylated spirit. The specimens should then be gummed, or glued, to sheets of stiff drawing paper, or to cards (about 10 × 18 inches), specially made for the purpose. The gum, or glue, should be made up with a little mercuric chloride, which also helps to repel insects. Alternatively, or in addition, the specimen can be sewn to the cards, or fastened to it with transparent adhesive tape.[1]

Each specimen should be labelled with at least: (*a*) the name and family of the species; (*b*) the name of the person, or body, which has identified the specimen; (*c*) the place and date of finding; and (*d*) the name of the finder.

Fruits or other bulky material associated with the specimen may have to be labelled and stored separately, but small seeds can be put in an envelope and attached to the mounting card.

Insects—These are best killed in a wide-mouthed bottle containing a suitable poison. A killing-bottle is easily made as follows. Some plaster of Paris is stirred to a thin paste with a 20 per cent. solution of potassium cyanide (the 'commercial' mixture of potassium and sodium cyanides is satisfactory) and quickly poured, to a depth of about ½-inch, into the bottom of the bottle, where it soon sets hard. The bottle should have a screw-cap or a well-fitting air-tight stopper, when it will remain effective for some months.

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[1] Specimens should not be mounted if they are to be sent to an expert for identification, or if the school co-operates with a herbarium (such as that of the botany department of a university) under professional supervision. The experts prefer to mount specimens according to their own systems.

A captured insect merely becomes insensitive when first put into a killing bottle, so it should be left for a few hours until it is dead. It may then be removed to a setting-board. A good substitute for the usual 'board' with half-round groove consists of two sheets of compressed cork, or thick cardboard, with a gap between their edges, fixed on a third sheet, as shown in Figure 63. The setting-board should be just large enough to hold the insect satisfactorily. A long thin pin, of the 'entomological' type, is then pushed through the middle of the insect's thorax, securing it in position in the groove. The wings, legs and antennae are then spread out carefully by means of seekers or fine tweezers, and kept in place by narrow strips of paper. (The strips are held down by pins, which must not touch the insect.) The specimen must now be dried thoroughly—not always an easy matter in the tropics, unless the setting-board can be left in a desiccator for some days. When it is dry the strips of paper are removed, as the various parts of the insect will now remain in place. It tends to be brittle, so no attempt should be made to move the thorax pin. By means of this pin the insect is lifted from the setting-board and pinned in a suitable position on the mounting-card. This is a sheet of cardboard or compressed cork previously cut to fit the bottom of a flat tin or other suitable box, the lid of which may be replaced by a glass top—by the method described under '*Collecting boxes*', page 231.

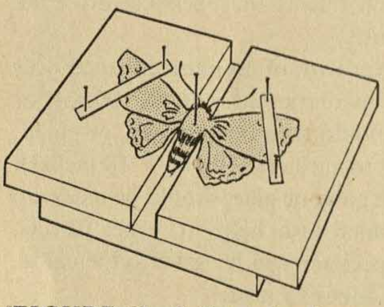


FIGURE 63.—Setting out an insect specimen

The preservation of specimens in the tropics is somewhat difficult, the chief problem being to prevent the attack of various kinds of ants. Some minute species seem eager for viscera, fresh or dried, and determined to remove everything except head, thorax and wings. The specimens must be kept, therefore, either in ant-tight cases, or in cases on some support completely surrounded by liquid. (Water requires frequent replacement owing to evaporation, and a layer of oil or disinfectant to prevent mosquitoes from breeding. Disused engine-oil, from a car sump, needs much less attention and is just as effective as water.) Probably the best answer to the problem is to keep the insect boxes on a table with its legs standing in tins of oil or disinfectant. The legs remain clean and dry if they stand on smaller tins inverted in the middle of the liquid. Ants and other harmful pests are unable to cross the liquid surface.

Other biological specimens—Amphibians, reptiles, birds and mammals are killed with chloroform, a pad of cotton wool, soaked in the liquid, being placed in the containing box. Mammals can be preserved in either 70 per cent. alcohol or 4 per cent. formalin. Amphibians, reptiles, molluscs and crustaceans are most suitably preserved in alcohol.

The cleaning of small skeletons, and the removal of viscera from large horny beetles, are jobs which, in the tropics, can be left to ants. The dead creatures are exposed in a suitable place. Their presence is soon detected by various ants, and before long a perfectly cleaned specimen remains. Bones can be scrubbed with an old toothbrush; bleaching powder should first be applied, and then hydrogen peroxide.

Corks—Before use, and before boring, corks should be softened by placing them on the floor and rolling them to and fro under the foot.

Corks can be made reasonably air-tight by soaking in a bath of molten paraffin wax. (The wax is hot enough when it begins to smoke.)

Boring of corks—This should be done with the borer held horizontally. Not too much force should be used, but the borer twisted a great deal. The borer should be worked part way through the cork from one end, then, to meet the first cut, from the other end. The borer and cork should be kept wet during the process.

Coloured light—Gelatine filters are apt to crack. The colours of the red, green and blue electric lamps, such as are often used for decorative illuminations, are less pure but are almost as satisfactory for coloured shadow effects. The colour of these bulbs is fairly durable. Each lamp is easily screened by mounting it in a cardboard (e.g. blackboard-chalk) box.

Density determination with a pencil—The density of a liquid can be found by floating a pencil, vertically, point upwards, in the liquid, and then in water. The ratio of the lengths immersed in the two liquids gives the specific gravity. The liquid is usually placed in a measuring cylinder. It is rarely that, without advice, a student will fill the cylinder sufficiently full to enable the pencil, while floating, to be handled conveniently.

Drying of apparatus—After washing glass apparatus it is best to let it drain on a rack and leave it to dry. But, if the apparatus has to be dried quickly, the process can be hastened by rinsing it out with a little methylated or industrial spirit after ordinary washing. Whether wet with water or spirit the apparatus can be dried still more rapidly by blowing a current of air through it by means of foot-bellows. If the air first goes through a heated tube the time of drying can be very considerably reduced; but glassware never looks quite so clean when hot air is used to dry it (see Figure 64).

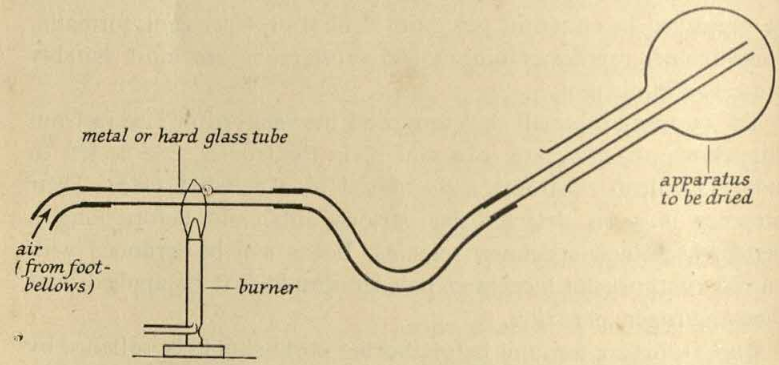


FIGURE 64.—A method of drying out apparatus

Flexible electric cable (‘*flex*’)—The frayed ends of the outer cotton or silk covering can be kept tidy by applying a drop of liquid glue to the frayed material and twisting it around, with the glue, between the fingers.

Galvanometers—These will only carry a very small current, usually about one-hundredth of an ampere. They are generally used with a high resistance in series, or a low resistance in parallel (a shunt). If the instrument is used to determine the moment when no current is passing in a circuit (e.g. with Wheatstone's bridges, 'Post Office' boxes, etc.), it should at first be protected by connecting a piece of copper wire across the terminals. The null point is found approximately. The copper wire is then removed and the full sensitivity of the instrument allowed to come into play.

Pupils should not be permitted to use one of these sensitive instruments without the wire shunt until the teacher has checked the circuit and given permission for it to be removed.

Hydrogen balloons—In filling a toy balloon with hydrogen the usual thistle funnel can be replaced by a funnel fitted with a tap. The delivery tube should be of as large a diameter as possible. The end of the balloon tube should be tied to the very end of the glass tube. This allows the final tying-off of the balloon to be done without first removing it from the glass tube. The acid is run into the vessel and the tap closed. The tap should be opened again the moment the balloon is tied off (see Figure 65).

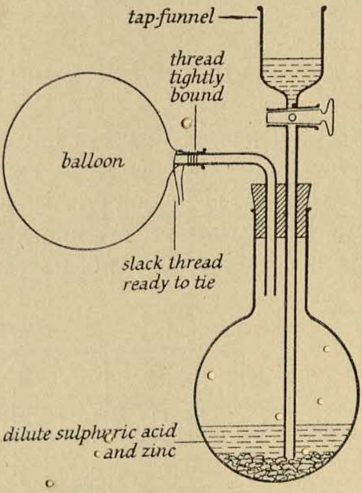


FIGURE 65.—Filling a hydrogen balloon

Labels—It is best to buy ungummed labels for use in the tropics. The label is fixed to the bottle with paste, or gum, and allowed to dry thoroughly. It is then painted over with molten paraffin wax, using one stroke of a flat, wide brush. The wax is at the right temperature when it begins to smoke. The excess wax around the edges of the label can be scraped off with a knife, leaving the label under a slightly larger rectangular layer of wax.

Lens, hand—Pupils often find difficulty in holding lens and object steady, and so fail to keep the image in focus. Control is much easier if thumb and forefinger of one hand hold the object, and those of the other hand hold the lens, and the tips of the middle fingers are pressed together (Figure 66).

The use of a watchmaker's lens has been discussed on page 240.

Appreciation of magnification can only come gradually, and pupils should therefore have plenty of practice with hand lenses before attempting to use a microscope. Moreover, in a General Science course the hand lens is sufficient for most purposes.

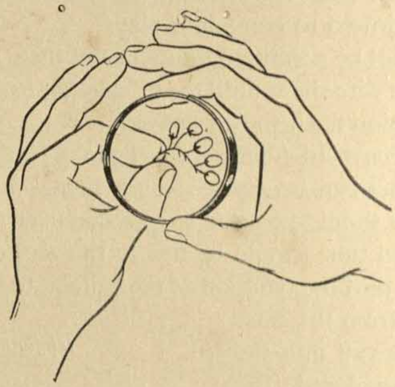


FIGURE 66.—How to hold a lens and an object

Levers—It is common practice to bore a hole in the middle of a bar, 12-inch ruler or 50-centimetre scale, in order to pivot it for experiments on moments of forces. It is more satisfactory, and the system is more stable, when the fulcrum is situated close to the top edge of the bar (see Figure 67).

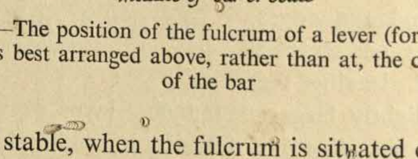


FIGURE 67.—The position of the fulcrum of a lever (for experiments on moments)—it is best arranged above, rather than at, the centre of gravity of the bar

Magnetized knitting-needle suspension—The needle is pushed through a short length of bicycle-valve tubing, and a *brass* pin is stuck through the rubber at right-angles (see Figure 68). The head of the pin is nipped off with pliers, and the position of the knitting-needle adjusted until the pin is at the point of balance.

Mercury—Air bubbles appear in a tube which is being filled with mercury. To remove them the tube is closed with the finger, before it is quite full, and inverted to allow a large air bubble to travel up it. When the tube is turned up again the large bubble reverses its track, collecting the smaller ones as it moves upwards and escapes. The small amount of mercury needed to fill the tube is then added.

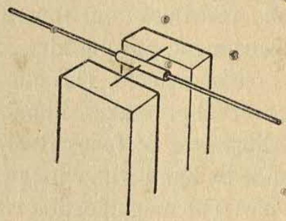


FIGURE 68.—The suspension of a magnetized knitting-needle

Mercury spilt on tray, bench or floor, may be recovered by sucking it into a small 'wash-bottle' (see Figure 69).

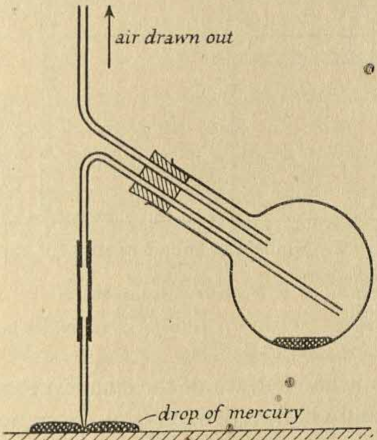


FIGURE 69.—The recovery of spilt mercury. (Air is withdrawn from the 'wash-bottle', e.g. by means of a filter-pump)

Microscopes—Young pupils are often fascinated by a microscope, but usually benefit very little from its use, as time and experience, as well as much practice in technique, are required for the appreciation of the magnification. Frequent use of hand lenses is the first essential.

Only the patient skill of the expert can bring much profit from the use of a high-powered microscope, and to provide one is usually misguided enthusiasm on the part of a teacher of General Science. Suitable slides are seldom made by amateurs, for the sections are generally too thick and thus appear opaque. Instead of such a costly instrument, an objective of 1-inch focal length with eyepiece (× $\frac{1}{6}$) is recommended. This allows inspection of the whole area beneath a cover slip, makes illumination comparatively easy, means that adjustment of focus is not critical, and permits movement of the slide by hand with enough control to retain the object in the field of view. The magnification is quite sufficient to show the main features of insects, the shape and surface of the smallest seeds, typical specimens of pollen, and characteristic crystal formations. The rule is: *use the least magnification which will serve the particular purpose.*

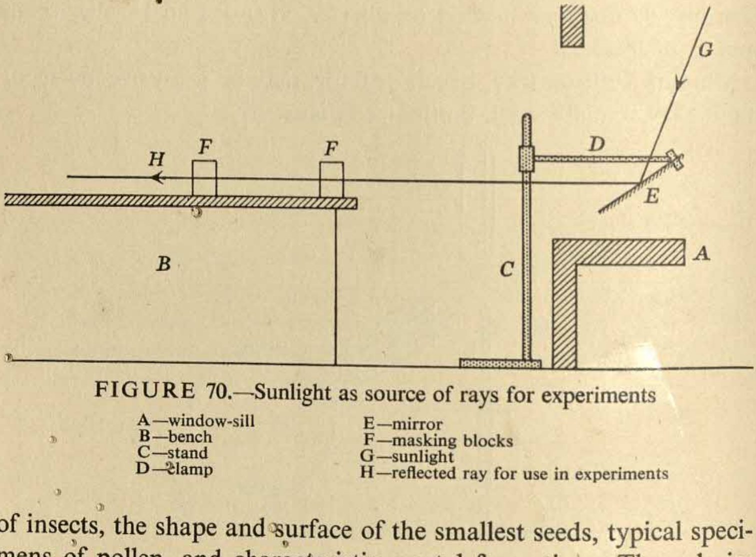


FIGURE 70.—Sunlight as source of rays for experiments

A—window-sill
B—bench
C—stand
D—clamp
E—mirror
F—masking blocks
G—sunlight
H—reflected ray for use in experiments

A teacher should try to train his pupils in correct microscope technique as soon as they begin to use the instrument, however low its power. The objective is marked $\frac{1}{4}$ inch or $\frac{1}{2}$ inch or 1 inch, for example, to show the distance between lens and object when the latter is in focus. The instrument should *always* be arranged so that the distance is less than this, and then, as the observer views the slide, the adjusting screw should be turned so that the objective is racked *away* from the slide. Risk of damage to the lens is eliminated by following this procedure, as the objective cannot then be pressed down on the slide. Pupils should also be taught to keep *both* eyes open, so that they can learn to observe with one while using the other to draw a sketch of the image. For this reason the microscope should be placed so that the eyepiece is about 12 inches above bench level.

Pendulums—To suspend a pendulum bob by a thread so that the length does not vary as it swings, the thread should be gripped between two flat, sharp-edged surfaces (e.g. two microscope slides), held firmly together in a clamp (see Figure 12, (*d*) and (*e*), page 99).

Rays of light—The phenomena and laws of reflection and refraction can be demonstrated by means of the usual experiments with pins, but the use of rays of light gives more direct and impressive results. (*a*) Sunlight is effective when reflected through a window from a mirror clamped on a tall stand. The mirror is arranged so that the reflected beam passes across the surface of the bench (see Figure 70). The beam is very bright and readily visible even in a very light room. The disadvantage of the method is that the relative position of the sun changes so quickly that frequent adjustments of the mirror are essential. A fairly sharp-edged ray is produced by using two pairs of masking blocks (as in the case of an electric lamp—Figure 71 (*c*)—which is the most convenient source of light). (*b*) A 6- or 12-volt supply of electricity, from accumulators or a mains transformer, may be used to light a car headlamp bulb (wattage 12 to 36). The lamp is arranged so that the plane of the filament is vertical and at right-angles to the required direction of the ray (see Figure 71 (*a*)). (*c*) With mains A.C. supply it is best to use a clear (*not* opaque) glass bulb, arranged so that the 'horse-shoe' filament is in a vertical plane with its edge towards the slits (see Figure 71 (*b*) and (*c*)). (*d*) In the absence of other sources of current, an electric torch may be used, but it should be switched on for periods as short as possible, in order to lengthen the life of the dry cells. The beam of light should be 'focused' to its narrowest, before passage through the slits, to give maximum intensity of light.

Rubber—Petrol, Vaseline and other petroleum products cause rubber tubing and corks to perish rapidly. Thus it is unwise to use Vaseline as a lubricant for slipping rubber tubing on to glass tubing. Special rubber lubricant may be purchased—and if this is

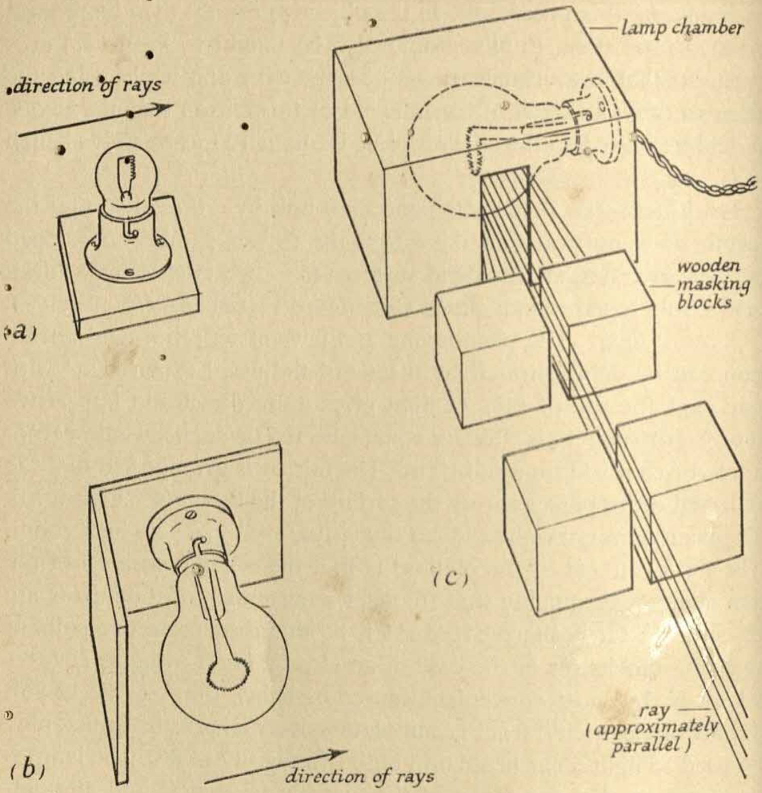


FIGURE 71.—Rays from electric lamps

(*a*) Car headlamp bulb in batten holder on stand
(*b*) Ordinary mains lamp in batten holder on stand
(*c*) Masking blocks to produce an approximately parallel ray

Note—In all cases the lamp should be in a ventilated chamber with aperture for the beam.

not available saliva may be used. Car brake fluid also serves the purpose.

Rubber should be kept well dusted with French chalk, in a box or drawer, to prevent rapid deterioration in hot climates. Strangely enough, it may also be stored in kerosene *vapour*, as long as precautions are taken to keep it clear of the liquid. This may be done by placing a shallow dish of kerosene on the bottom of a small cupboard, with close-fitting door, and putting the rubber on perforated shelves.

Scale-pans—These may be made from the lids of tins, suspended by stout thread or thin string. To make sure that the pan hangs horizontally three long strings should be attached through three holes, bored at equal distances from each other in the rim. The lid, with a heavy weight in it, is put on a table. The strings are then held taut at a point vertically above the centre of the lid and carefully knotted together. Keeping the strings together, knots are made nearer and nearer to the lid. When the final knot is sufficiently near the lid, the string is cut above the second knot from the tin (see Figure 72).

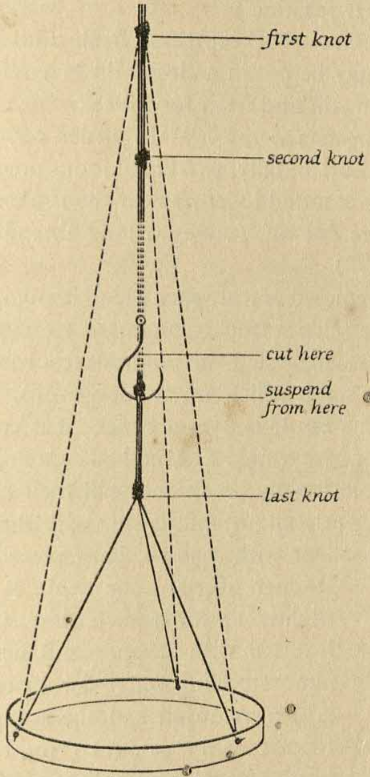


FIGURE 72.—How to hang a scale-pan

Soldering fluxes—The following are suitable:
tallow for joining lead to lead, or brass to lead;

rosin or '*killed spirits*' for joints in brass, copper, tinplate, zinc; '*killed spirits*' for iron and silver.

After soldering, 'killed spirits' should be washed off with water, and rosin—or 'fluxite'—with methylated spirit. ('Killed spirits' consist of concentrated hydrochloric acid to which zinc was added until there was no further reaction.)

Specimens, botanical—To keep these fresh until there is time to press them, they may be put in a closed tin in a refrigerator, where they readily remain stiff and fresh for a week.

Stirrup for suspending a magnet—In order to ensure that the magnet will hang horizontally, two equal loops are made in a piece of thread, and then knotted together near the top ends of the loops. The spare ends are cut off, leaving a long thread to suspend the loops (see Figure 73).

Stoppers—The removal of a stopper which is stuck in the neck of a bottle is a task the science teacher often has to undertake. The following methods are suggested, in progressive order of severity. If the bottle contains solids which are not dangerous, the methods can be applied while the bottle is over a bench; if it contains liquid, it should be held in or over a sink. The methods are not always successful, and bottles occasionally break and spill their contents. (*a*) The stopper is tapped gently all around its side with the wooden handle of any available tool, or with a small, hard piece of wood. If the stopper overlaps the neck, it may be struck slightly upwards each time. (*b*) The bottle is inverted with stopper and neck immersed in almost boiling water for 15 to 20 seconds. It is then removed and the stopper immediately tapped as in (*a*). (*c*) (Not to be used with bottles containing inflammable or dangerous liquids or solids.) The bottle is held at an angle, and rotated so that a candle flame deposits

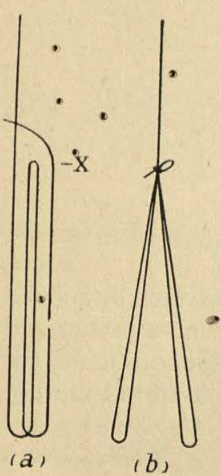


FIGURE 73.—Stirrups for suspending a bar-magnet

(*a*) Equal loops in the string, drawn together at X, and—

(*b*) tied into a knot

a layer of soot all around the neck. Method (*a*) is applied after a few moments. (*d*) If the stopper still refuses to loosen, it may be necessary to cut off the neck of the bottle. To do this a series of file marks are made around the neck with a sharp triangular file. The end of a piece of glass rod, or drawn-out tubing, is heated strongly in a flame and applied, while hot, to a file mark. A few attempts will usually cause a slight crack to start. The process is then repeated at the next file mark, or the first crack is encouraged to travel around the neck by movement of the hot point of glass along the crack in the desired direction. The neck is given a sharp knock with a piece of wood as in (*a*).

Thermometers—If these are left for some time in a rubber cork, they are often difficult to remove. A cork borer, of a size such that the thermometer passes through it, is used to rebore the cork, while the thermometer remains inside the borer. The thermometer then comes out with a thin ring of rubber which may be scraped off.

Tropical conditions—There are many causes of trouble in a laboratory, especially during a wet season in the tropics. Materials perish, papers stick together, instruments rust, specimens go mouldy, lenses develop a fungus which quickly renders them useless and ruins their accurately ground surfaces. In addition, ants, termites and other insects continue their endless work of destruction.

Whatever can be kept in an air-tight container should be so kept. Glass jars, such as specimen jars with lids well greased, are ideal. Screw-capped bottles, e.g. those which have contained sweets, are very useful. Metal containers, such as biscuit tins, cake tins, etc., can be rendered fairly air-tight by strapping the joint between the lid and container with insulating tape.

Lenses of microscopes should be kept in a desiccator when not in use. Needles can be inserted in a piece of material in which some Vaseline has been rubbed. Metal instruments such as screw gauges, vernier callipers, tuning forks, etc., should be greased. The screws of retort stand bosses, rings and clamps should be oiled frequently. Scalpels should be smeared with Vaseline and kept in a case. The metal parts of tools should be rubbed over with an oily rag.

Paste, gum and glue should contain some chemical to make them repellant to insects. Such adhesives are sold specially prepared for the tropics. But, if the teacher makes his own, the addition of a very small quantity of a solution of mercuric chloride, during the preparation, is generally effective.

Biological specimens seem to be the favourite food of some species of minute ants. Dusting with D.D.T. deters the ants but spoils the look of the specimens. If mounted insects are left unprotected, these almost invisible ants eat out the intestines and the specimens disintegrate. Suggestions for dealing with this problem are given on pages 250–51.

Voltmeters—See '*Ammeters*', page 245.

NOTES ON SOME COMMON CHEMICALS

A list of chemicals which may be required in a General Science course is given in Appendix E, part II, page 331, with brief notes on danger, poisons and absorption of moisture.

The teacher must also remember other points, such as safe storage, the characteristics of different grades of purity of a substance, and the effects of certain properties, which sometimes have additional importance in the tropics. The list below gives some typical examples and contains other useful hints.

Acetone—This is inflammable and very volatile, and should therefore be kept in air-tight, screw-capped bottles not exceeding 250 ml. capacity.

Acid, acetic, glacial—Melting point 17° C.: below this temperature it is a crystalline solid, which must be melted *slowly* with the stopper removed from the bottle. The fumes are somewhat poisonous and should not be breathed.

Acid, carbolic (*Phenol*)—It is deliquescent and also tends to turn pink. Although its purity is not noticeably affected, it is best kept in a dark, air-tight bottle.

Acid, hydrochloric; acid, nitric; acid, sulphuric—For the comparatively small quantities of these three acids required in a laboratory, it is advisable to obtain the 'pure' grades. They cost very little more than the 'commercial' ('technical' or 'industrial') varieties, and there is less likelihood of confusion.

Alcohol, ethyl—The substance varies greatly in cost, according to Customs and Excise regulations in different countries, and can be obtained in several degrees of purity. It is usually sold under the following names:

Absolute alcohol, the pure liquid, which is always very costly and is seldom needed. ('Commercial' iso-propyl alcohol is a satisfactory substitute for preserving biological specimens or dehydrating those to be mounted in Canada balsam.)

Rectified spirit, which contains about 10 per cent. by weight of water. Like absolute alcohol, it should be stored in air-tight bottles.

Methylated spirit, the common form, which contains 5 per cent. of methyl alcohol and other impurities, including a dye.

Industrial methylated spirit, which contains 5 per cent. of methyl alcohol, but is free from other impurities. Thus it is suitable for many laboratory purposes, and, if the difference in cost is not prohibitive, should be bought in preference to the common variety.

Alcohol, methyl (*wood spirit or wood naphtha*)—This poisonous, highly volatile liquid, used as an adulterant in methylated spirit, must never be confused with mineral naphtha, which is an entirely different substance.

Aluminium wire—The thin wire is useful for making riders for balance beams.

Ammonia solution (*ammonium hydroxide or 'ammonium hydrate'*)—The usual concentrated form has a specific gravity of 0·880 and is dangerous for tropical use. The opening of a bottle can release gas with explosive violence. It is better and safer to use a less concentrated solution, e.g. S.G.: 0·910, and even then the greatest care must be taken in handling it.

Ammonium bicarbonate—The substance very rapidly decomposes in air, so must be kept in an air-tight bottle.

Bleaching powder—This is deliquescent and also quickly decomposes in air. It should be bought and kept in small, sealed containers.

Bromine—This is purchased in 1-ml. glass ampoules, packed in an inactive white powder (such as kieselguhr) in a tin.

Calcium carbide—Being hygroscopic, 'carbide' rapidly reacts with moisture in the air to produce acetylene. It should be bought and kept in small, sealed containers.

Calcium hypochlorite—See '*Bleaching powder*'.

Calcium oxide (*Quicklime*)—This, being hygroscopic, is readily slaked by the moisture of the air, so here again containers must be small and sealed to keep the substance in good condition.

Calcium sulphate (*Plaster of Paris*)—The substance will set hard and become useless unless it is kept sealed and very dry. It should be ordered in small containers, each containing not more than 250 g.

Carborundum paste—This is used in, and can be obtained from, garages.

Chloroform—The 'methylated' variety, which is about half the price of pure chloroform, is suitable for most purposes in a school laboratory.

Formaldehyde—The substance is volatile, and the vapour has a very irritating action on the eyes and throat. The solution tends to decompose, with the formation of formic acid, which may be neutralized, if necessary, by sodium bicarbonate.

Gelatin—This may often be bought locally, in food or grocery stores.

Gold size—This is obtainable from garages, where it is used on gaskets for making air-tight joints. Turpentine may be used to dilute it, and the bottle should be tightly corked.

Hydrogen peroxide—The solution should be kept in the dark, in well-stoppered bottles. The more dilute '10-volume' solution keeps better than the '20-volume' variety.

Indicators—The approximate range of the common ones is as follows:

Bromophenol blue	pH 3–4·5
Congo red	3–5
Methyl orange	3–4·5
B.D.H. 'Universal'	3–11
Litmus	5–8
Phenol red	7–8·5
Phenolphthalein	8–10

The commonest are:

Methyl orange	(for use with weak base and strong acid)
Litmus	(for use with strong base and strong acid)
Phenolphthalein	(for use with strong base and weak acid)

Naphtha (*mineral naphtha*)—The liquid in which potassium and sodium metals are kept is a mixture of hydrocarbons. It does not contain oxygen, nor does it absorb oxygen from the air.

Petroleum ether—This is a volatile and inflammable paraffin, of low boiling point, which can be used instead of the far more expensive (di-ethyl) ether to produce low temperatures by rapid evaporation.

Phosphorus (*yellow*)—The element must be kept under water in a bottle. It should be taken out of the bottle with tongs, placed in a dish of water, and cut under water. It should not be touched by the hand, as body temperature is high enough to ignite it.

Potassium cyanide—The commercial variety (mixed with sodium cyanide) is suitable for making killing bottles and for most other laboratory uses.

Potassium and sodium hydroxides—One 'stick' of each substance weighs about 20 g., and twelve 'pellets' about 1 g.

NOTES ON SOME LABORATORY SOLUTIONS

The science teacher (and the laboratory assistant) have to spend much time in the preparation of solutions. It is difficult to remember all the quantities required and the details of procedure, and it is a good idea if these are neatly printed on the labels of stock bottles. Notes on the making-up of some of the solutions, etc., in common use in the school laboratory, are given here.

(1) *Accumulator solutions*

(*a*) *Lead accumulator*—The specific gravity of the sulphuric acid in various conditions of the battery is as follows:—

State of battery	*Specific gravity*
Fully charged	1·28
Half charged	1·21
Discharged	1·15

The above figures are approximate. The recommendations of the makers, usually printed on the battery, should be followed. A rough guide to the making of a solution of sulphuric acid of specific gravity 1·28 is as follows:

Concentrated sulphuric acid is added slowly, with stirring, to a beaker two-thirds full of distilled water, until the solution is almost boiling. The solution is allowed to cool, and more acid is added, with similar precautions, until the solution is again almost boiling. After cooling to room temperature, the specific gravity is adjusted by the addition of more acid or more water, according to the hydrometer reading.

(*b*) *Nickel-iron* (*Nife*) *accumulator*—The specific gravity of the caustic soda solution is as follows:—

Specific gravity when the battery is:—	*Temperature*		
	60° C.	80° C.	100° C.
(*a*) first filled	1·190	1·185	1·180
(*b*) working and fully charged . .	1·170	1·165	1·160

4 lb. (2 Kg.) of caustic soda are dissolved in 1 gallon (5 litres) of water to provide a solution of the approximate strength required. It can then be diluted with water as necessary.

(2) *Bench reagents*

(*a*) *Hydrochloric acid* (approximately 2N)—200 ml. of concentrated hydrochloric acid solution are made up to 1 litre with water.

(*b*) *Nitric acid* (approximately 2N)—130 ml. of concentrated nitric acid are made up to 1 litre with water.

(*c*) (i) *Sulphuric acid* (approximately 2N)—60 ml. of concentrated sulphuric acid are poured slowly and carefully into 1 litre of water.

(ii) *Sulphuric acid* (approximately 5N, for making hydrogen with zinc)—150 ml. of concentrated sulphuric acid are poured slowly and carefully into 1 litre of water. (The solution will get very hot and the operation is best carried out with the container standing in cold water in a sink.)

(*d*) *Potassium hydroxide* (approximately 2N)—6 sticks (about 120 g.) are dissolved in 1 litre of water. The solution should be kept in a bottle with a rubber cork.

(*e*) *Sodium hydroxide* (approximately 2N)—4 sticks (about 80 g.) are dissolved in 1 litre of water. The solution should be kept in a bottle with a rubber cork.

(3) *Common reagents*

(*a*) *Fehling's solution*—Two solutions, A and B, are prepared: A. 35 g. of copper sulphate crystals are dissolved in 1 litre of distilled water.

B. 173 g. of sodium potassium tartrate and 120 g. of sodium hydroxide are dissolved in 1 litre of distilled water.
Equal volumes of A and B are mixed as required. A and B keep well if they remain separate, but not after mixing.

(*b*) *Iodine solution*—About 6 g. of potassium iodide are dissolved in 100 ml. of water, and then 2 g. of iodine crystals are dissolved in the solution.

(*c*) *Pyrogallol* (for absorbing oxygen)—Two solutions, A and B, are made. Solution A contains 5 g. of pyrogallol (known to photographers as 'pyro', and to chemists as 'pyrogallic acid') in 100 ml. of water. Solution B contains 25 g. (about 1¼ sticks) of potassium hydroxide in 100 ml. of water. Equal volumes of A and B are mixed when wanted. If the two solutions are separate they will keep indefinitely, but the solution which results on mixing will not keep.

(*d*) *Sea-water*—A useful substitute for sea-water can be obtained by dissolving the following in 2 litres of water:

45·0 g. sodium chloride
3·5 g. magnesium sulphate
5·0 g. magnesium chloride
2·0 g. potassium sulphate

(*e*) *Silver nitrate solution*—3·5 g. of silver nitrate are dissolved in 100 ml. of distilled water. If distilled water is not available, rainwater should be used. (Rainwater which is running off a clean, rainwashed roof should be collected in a clean vessel such as an enamelled bucket. It should be boiled, and either filtered, or allowed to settle, when the clear liquid may be siphoned off.)

(4) *Culture solution* (*for plants*)

The following salts, of *purest* quality, should be dissolved together in 1 litre of distilled water:—

0·70 g. potassium nitrate
0·25 g. calcium sulphate (hydrated)
0·25 g. calcium hydrogen phosphate (hydrated)
0·25 g. magnesium sulphate (hydrated)
0·08 g. sodium chloride
0·005 g. iron (ferric) chloride (hydrated)

To the solution should then be added:—

1 ml. 0·06 % boric acid solution
1 ml. 0·04% manganese chloride solution.

(5) *Electro-plating solutions*

(*a*) *Copper*—About 100 g. of copper sulphate crystals are dissolved in about 300 ml. of water. 6 g. of potassium bisulphate and 5 g. of potassium cyanide are then added. The solution is made up to 450 ml. (The solution should be kept cold while it is being made.)

(*b*) *Silver*—About 20 g. of sodium cyanide and 40 g. of crystalline sodium carbonate are dissolved in about 500 ml. of water. About 20 g. of silver nitrate are dissolved separately in 250 ml. of water. The second solution is added slowly to the first, and the mixture made up to 1 litre.

(The *current* to be passed through the solutions depends on the area of the electrode upon which the metal is to be deposited. It should not exceed about 2 amps. for 100 sq. cm. of surface. It should be proportionately less if the electrode is smaller. The deposited metal will appear dull. It will not present the expected bright and shining appearance until it has been burnished, by rubbing, for instance, with a bone spatula or some other hard smooth, non-metallic, surface.)

(6) *Indicators*

(*a*) *Litmus*—This is usually sold in small cubes. 100 g. are ground up with 500 ml. of water until as much has dissolved as possible. The mixture is boiled, and allowed to cool and settle. The clear liquid is then poured, or siphoned, off and made up to 1 litre with water. One or two drops of chloroform are added. The solution should be kept in a bottle fitted with a one-holed cork, through which passes a bent glass tube, so as to admit air but exclude dust. It should be stored in a dark cupboard.

(*b*) *Methyl orange*—1 g. is dissolved in 1 litre of water.

(*c*) *Phenolphthalein*—2 g. are dissolved in 600 ml. of rectified spirit, and made up with water to 1 litre.

(*d*) *Starch*—1 g. of starch is mixed with some cold water to make a very thin paste. This is then added, drop by drop and with constant stirring, to a beaker containing 100 ml. of boiling water. If the liquid is boiled too fiercely the beaker will crack. The solution keeps in good condition for only a few days.

(7) *Stains*

In general it is preferable to buy stains ready made up in solution, but the following are useful recipes:

(*a*) *Aniline sulphate*—A few drops of dilute sulphuric acid are added to a saturated solution.

(*b*) *Borax carmine*—4 g. of borax are dissolved in 100 ml. of water. 3 g. of carmine are added and warmed until dissolved. 100 ml. of 70 per cent. ethyl alcohol are then added and the solution filtered.

(*c*) *Safranin*—1 g. is dissolved in 100 ml. of water *or* 100 ml. of 50 per cent. aqueous ethyl alcohol.

(8) *Useful preparations*

(*a*) *Cement*—A useful 'cement', e.g. for the repair of broken glass or china, can be made by dissolving celluloid or unwanted photographic films in acetone. But it is probably wiser, and cheaper in the long run, to buy a tube of such cement from a hardware store. The type of cement best suited for the purpose can be recognized by the fact that it smells strongly of acetone or amyl acetate.

(*b*) '*Dead black*'—This is useful for painting the inside of 'light' apparatus, so that unwanted reflected light may be eliminated, rays made less diffused, and images made sharper. Lamp black is mixed with gold size, and turpentine added, with constant stirring, until the mixture is sufficiently thin for use as a paint.

(*c*) *Fluorescin solution*—(This is useful because the track of a ray of light travelling through a solution of fluorescin can be seen very clearly.) 1 g. of fluorescin is dissolved in 100 ml. of industrial, or methylated, spirit.

(*d*) *Heat sensitive paper*—A solution of cobalt chloride in water is added to a solution of ammonium chloride in water. (The proportions do not matter.) The solution is diluted until it is pale pink. Filter paper soaked in the solution and allowed to dry appears to be almost colourless, but on heating it will turn a bright green colour.

(*e*) *Silvering solution* (for depositing a bright silver mirror on glass)—Firstly, 12·5 g. of silver nitrate are dissolved in 100 ml. of water. 32·5 g. of sodium potassium tartrate are dissolved separately in 100 ml. of water. The two solutions are mixed, warmed to 55° C., and kept at that temperature for 5 minutes. The mixture is then cooled and the clear liquid poured off from the precipitate and made up to 200 ml. for solution A. Secondly, 1·5 g. of silver nitrate are dissolved in 12 ml. of water. Dilute ammonium hydroxide solution is added until the precipitate first formed is almost entirely redissolved. The liquid is made up to 200 ml. for solution B. The solutions A and B are then mixed. (The surface to be silvered, having been cleaned very carefully to free it from all traces of grease, should be suspended upside down in the solution, just below the surface. The solution can be put into a clean test-tube, or small flask, and a mirror deposited on the inside of the vessel. The solution can be slightly warmed to hasten the deposition of the silver.)

(*f*) *Soap solution* (for making bubbles)—4 g. of Castile soap are dissolved in 80 ml. of water, without warming, and 20 ml. of glycerin are then added. The solution will keep for some weeks.

Organization of storage and stocks

Most of the problems of storage and arrangement of apparatus and equipment have already been discussed, but a few points require further emphasis:

(*a*) *Standardized apparatus* should be the aim as far as possible. It is advisable, for example, to use only certain sizes and types of bottles (with sandblast labels for the reagents in common use), beakers and flasks, corks and rubber stoppers of corresponding dimensions, glass and rubber tubing of appropriate diameter, stands, magnets, lenses, etc. This system makes the assembly of apparatus from its constituent units easier and quicker, simplifies storage and checking, and facilitates replacement orders.

(*b*) *Resistance-glass* vessels and *high-quality porcelain* are to be preferred to cheaper varieties, as they usually prove to be more economical in the long run.

(*c*) *Specifications* of equipment must be carefully stated when orders are placed, if possible with catalogue numbers. For instance, it is essential to have burners manufactured for use with the particular gas supply, instruments of the correct units and capacity for the electrical supply in use, materials specially made for tropical conditions, etc.

(*d*) *Dangerous liquids* in large bottles, or other containers, need special care. Inflammable liquids (it should be remembered that these include stocks of petrol or kerosene), concentrated acids, etc., are most safely kept on the floor, and there should be regular inspection to ensure that stoppers are properly fitted and sealed. A separate, small, cool store, outside the main building, is to be recommended. The cement floor should slope gently towards the centre from two sides, the resulting groove itself sloping to a hole in the wall, from which any liquid may run into a sump (loose stones in a small pit). Thus any spilt liquid flows towards the middle of the room and can be seen at once. A further safeguard can be provided by standing large bottles of concentrated acids in buckets, bins, emptied oil-drums or tins, containing sand.

Keeping stock—Accurate records are necessary in order to make sure of replacements being ordered early enough for delivery at the right time. Moreover, the science teacher is responsible for the science apparatus and chemicals in the laboratories and stores. A suitable inventory is therefore essential. It is convenient to keep two books, one for apparatus and equipment, the other for chemicals. To make rapid checking possible, books of foolscap size are ruled as shown in Figure 74, and the items are entered in alphabetical order. (The lists of apparatus and chemicals in Appendix E. II, page 331, can be used as a guide.)

Plenty of space should be left between entries so that extra items can be inserted in their proper places. It is not wise to draw up such stock-books on the assumption that they will last for many years: it will usually be found, after three or four years, that the lists must be re-written. An approximate estimate of the number of pages (in proportion) required for each initial letter in an inventory is:

A—1
B—6
C—6
D—3
E—2
F—6
G—4
H—1
I, J, K—1
L—2
M—4
N—1
O—1
P—3
Q—0
R—2
S—4
T—5
U, V—1
W—1
X, Y, Z—1

Whether the teacher adopts this method or uses a card index, the simpler the system of entry the better. (Detailed stock cards, suitable for laboratories of large industrial concerns, are not necessary in a school.)

When the time comes to order a fresh supply of materials, reference to a well-kept stock-book can save a great deal of time.

(Book I) APPARATUS

	Date:	20/12/52	12/4/53	,,	Jan.–April '53	30/4/53	,,					
		Stock	*Added*	*Total*	*Reported broken or unusable*	*Checked by: (Teacher's initials)*	*Stock*	*Added*	*Total*	*Reported broken or unusable*	*Checked by*	*Stock*
Flasks, conical	250 ml.	27		27	2	√	25					
	500 ml.	11	12	23		√	23					
,, distilling	250 ml.	2		2	1	√	1					
	500 ml.	6		6		√	6					
flat bottom	150 ml.	21		21		√	21					
	250 ml.	19	6	25		√	25					

(Book II) CHEMICALS

	Date:	20/12/52										
		Stock	*Added*	*Total*	*Used*	*Checked by: (Teacher's initials)*	*Stock*	*Added*	*Total*	*Used*	*Checked by*	*Stock*
Mercuric sulphide	g.	25										
Millon's reagent	ml.	100										
Naphthalene, flakes	Kg.	1½										
,, , marbles	g.	400										
Nitre (see potassium nitrate)		—										
Oil, cedarwood	g.	25										
,, , linseed	W.Qt.	1½										

FIGURE 74.—Inventory books (typical extracts): one method of keeping stock records

Danger in the laboratory

The teacher's responsibility—In a well-organized laboratory, under careful and efficient supervision, accidents are very few and far between. As in every other sphere of life, risks cannot be entirely eliminated, but they can be reduced to a minimum. It is the responsibility of the teacher to ensure that the chance of accident is remote, and also to be prepared to deal with any which may arise. 'Did the teacher take reasonable precautions?' is the question properly asked when an accident has occurred. The physical and mental well-being of his pupils is the first concern of every teacher: because of the materials he uses, the science teacher has a special duty and responsibility. The community, and his fellow science teachers everywhere, expect him to conduct himself accordingly.

The following rules are a guide to suitable organization and procedure:—

RULES FOR THE SCIENCE TEACHER

(1) No class should be allowed to enter, or remain in, the laboratory in the teacher's absence. (In the case of young pupils, even a small group, or a single pupil, can seldom be trusted alone among so much interesting and tempting material.)

(2) The teacher must ensure that he is always in full and proper control of his class. (Quiet and orderly behaviour is even more important in the laboratory than the class-room. A good teacher will find opportunities of relating it to scientific methods.)

(3) A list of rules for pupils should be displayed prominently, both inside the laboratory and outside the door (see below). The teacher must make sure that all his pupils understand the rules and the reasons for them, and that they are strictly observed. (Deliberate, or repeatedly careless, disobedience must be punished.)

(4) The laboratory should be kept clean and tidy. There should be a place for everything, and everything should be in its place when not in use. Good, clear labels are essential. (Here, again, there is a connexion with scientific methods.)

(5) Apparatus and materials should be prepared in advance and be ready when the class enters the laboratory.

(6) The teacher must always give careful instructions for the use of unfamiliar apparatus or chemicals, repeating warnings if there is any danger, and make sure that he is understood. (Good technique should be constantly stressed until it becomes a habit.)
(7) Special warnings, with emphasis on the precautions to be taken, must be issued at the start of a lesson in which inflammable liquids, or other dangerous substances, are used.
(8) Correct procedure in the use of mains supplies of gas and electricity must be enforced. (This and similar points have already been discussed.)
(9) Materials for putting out a fire must be kept handy in definite places. Teacher and pupils should know how to use them quickly and correctly.
(10) A first-aid kit should be kept in each laboratory or adjoining preparation room, preferably in a separate cupboard. It must be kept in good condition, and the teacher must know how to use its contents.

The pupil's behaviour—It is part of the teacher's duty to see that pupils obey the rules for the proper and safe use of the laboratory. This is most effectively done through the teacher's example and precept. However, it is advisable to have a list of rules in clear, bold type, posted up prominently inside and outside the laboratory (see (3) above). The following is the sort of list recommended by associations of science teachers (the parentheses contain hints for explanation):—

LABORATORY RULES (FOR THE PUPIL)

(1) Nothing is to be removed from the laboratory. (Apparatus and materials are the property of the school. They are intended for special use in a particular place in the right way; they are often dangerous if otherwise treated.)
(2) Laboratory equipment and material is for use only in the laboratory. (If taken elsewhere it is easily lost, broken or misused, and is then not available for science lessons.)
(3) Apparatus and materials must be used only for the purposes sanctioned by the teacher in charge. In any experiment, pupils must stick to the instructions given and must not go beyond

them. (There is a risk of breakage, fire, explosion, etc. A scientist tries to acquire all the information possible before planning an experiment.)

(4) Any mishap—e.g. cut, burn, scald, substance in mouth or eye, or on clothes—must be reported to the teacher *at once*. (Further treatment, given immediately, may save much trouble and prevent pain or serious injury.)

(5) Breakages and faults in equipment must be reported to the teacher immediately. (It may be possible to put things right before there is more trouble, or to improve technique, or to avoid recurrence.)

(6) Loose or obscure labels must be reported to the teacher *at once*. (This will help to avoid mistakes.)

(7) It is essential to make sure that the name on a label is *exactly* the same as that of the object or substance required for the particular experiment. (The need for accurate observation should prevent carelessness and consequent mistakes.)

(8) Bottles must never be held by the neck or stopper. (The risk of breakage can be reduced.)

(9) Stoppers of bottles should be removed in the proper way and replaced at once. A stopper must always be put back on the right bottle. (There is otherwise a risk of introducing impurities and of causing chemical reaction.)

(10) The smallest convenient quantity of a substance is all that should be used in any experiment. (It is economical. Tests with dilute solutions are often more accurate than with concentrated; etc.)

(11) A substance taken into the mouth accidentally must be spat out at once and the mouth washed out with water. (There is a risk of poisoning or other injury.)

(12) Nothing must be tasted without definite instructions from the teacher. (As for (11).)

(13) Acid or alkali on skin or clothing must be washed off at once by plenty of water.

(14) At the end of an experiment, apparatus must be left clean and tidy in the place where it was found.

(15) Solid objects must not be put into a sink. (There is danger of blocking the waste-pipe, of chemical action, etc.)

(16) Waste of gas, water and electricity must be avoided. When supplies are not in use, all taps and switches must be turned off. (It is economical. Risk of accident is reduced.)

(17) The laboratory, benches and equipment must be left clean, neat and tidy. (See rule (4) for teachers, page 273.)

(18) When in doubt, the pupil must ask the teacher for help or advice at once.

N.B.—A pupil is entirely to blame for any accident resulting from inattention to the above rules.

A teacher may wish to add other rules, particularly in the case of a specialized laboratory. For instance, in the chemistry room it is advisable to include: the manipulation of a hot test-tube, the treatment of red-hot material, the disposal of hot concentrated sulphuric acid, the reactions of substances such as sodium, phosphorus, etc., and so on. A list of precautions against fire is to be recommended, and an example is given in Appendix G, page 347.

Emergencies

Prevention is better than cure: that should be the teacher's motto. In spite of the best teaching, example, technique and lists of rules, however, an occasional accident may happen. The teacher must be prepared to deal with the situation, and the following notes are a guide to appropriate action.

Spilt liquids—Even harmless liquids should be washed away and dried up as soon as possible.

If an *inflammable liquid* is spilt, all flames should be put out at once and not be relit until the cleaning up is complete. Advice on storage, and other precautions to be taken, have already been mentioned.

Acids should be neutralized at once by the application of sodium bicarbonate or powdered calcium carbonate. The mixture should be swabbed up with plenty of water after effervescence has ceased. Acid spilt on clothes should be treated immediately with dilute ammonia solution (ammonium hydroxide) and then washed off with plenty of water.

Caustic alkalis should be neutralized by pouring on excess of dilute acetic acid. Floors or benches should then be swabbed, or clothes thoroughly rinsed, with much water.

Fire—Methods of reducing the risk of outbreaks of fire are given in Appendix G, page 347. Rules and regulations are a necessary discipline in daily life as in the laboratory. But there is no need for pupils to have to regard them as an arbitrary list of 'do's' and 'don'ts'. As often as possible they should be explained, used as examples of principles and as principles for which there are numerous examples. 'The prevention and treatment of outbreaks of fire' is an important topic in everyday life as well as in the laboratory. It may be linked with lessons on burning, flames, rusting, breathing, air, oxygen, etc. Stress should be laid on the necessity for the exclusion of air in attempts to subdue a fire, and to illustrate the principle a teacher may quote such instances as:—

Case of fire	*First step in treatment*
A person's clothes . . .	Wrap with heavy cloth or blanket
In a house	Keep all doors and windows shut
In a mine	Stop ventilation; seal it off
In a ship's hold . . .	Close the hatches

The use of a fire extinguisher simply provides a 'blanket' of heavy gas or foam to cut off the flames from the air.

If fire does break out, rapid action must be taken in the following ways:—

(*a*) A person whose clothes are on fire should be wrapped tightly in a fire-proofed blanket and rolled on the floor. (Any large blanket, coat or cloth will do as a substitute. Access of air to the flames must be cut off, so on no account must the person concerned be allowed to rush about.)

(*b*) An ordinary fire (of paper, wood, etc.) may be put out at once by sufficiently large quantities of water.

(*c*) If inflammable substances ignite in a beaker or flask, the fire can often be extinguished and prevented from spreading by pressing a sheet of asbestos over the mouth of the vessel.

(*d*) Small fires due to oil, phosphorus, sodium, etc., can often be put out by smothering them with large quantities of dry sand or soil.

(*e*) If the fire is due to gas from the laboratory supply, or if the fire is near to a gas pipe, or if there is danger of the fire spreading, the mains stopcock should be turned off at once.

(*f*) If the fire is due to electricity, the current must be switched off at the mains switch immediately. (Every teacher and pupil should know the exact position of the mains switch and how to turn it off.)

(*g*) In the case of any but the smallest fires, pupils should be sent out by the exit farthest from the fire. (Occasional fire-drill is advisable to ensure good discipline.)

(*h*) If there is the slightest danger of a large fire, all doors and windows should be shut to reduce the flow of air.

(*j*) Should there be any chance of failure by the above methods, fire extinguishers must be used promptly—but they must be of the right type:—

(i) Soda-acid (carbon dioxide) is suitable for ordinary fires.

(ii) The foam type is usually satisfactory for oil, sodium, etc.

(iii) The carbon tetrachloride type is necessary for fires due to live electric circuits. The fumes from such an extinguisher are poisonous, and the laboratory must be well ventilated as soon as the fire is out.

Accidents and first-aid—Insistence on the correct methods of using apparatus and materials (already emphasized in many places in this book) prevents many accidents. However, the teacher must be prepared to give first-aid if an accident does occur. Two main points must be remembered:—

(1) Treatment must be prompt, appropriate and efficient.

(2) The patient should be examined by a doctor at the earliest possible moment when:—

(*a*) there is injury to an eye;

(*b*) there is any risk of an injury proving serious;

(*c*) the teacher is in any doubt. (If no doctor is available, the patient should be taken at once to the nearest dispensary or clinic.)

A short course in first-aid is helpful to any science teacher and gives confidence in dealing with an accident. A first-aid cupboard, readily accessible, kept well stocked, is essential. It is best to have a separate cupboard (one on the wall of each laboratory or preparation room), preferably with a red cross painted on a white ground to draw attention to its purpose. Dimensions of 2 feet × 2 feet × 6 inches are suitable, a shelf being fitted in the middle. A lock is not to be recommended owing to the possibility of a missing key in an emergency. A list of materials for a *first-aid kit* for the laboratory is given in Appendix H, page 349. The kit must be kept scrupulously clean and in first-class condition. (Care is necessary: for instance, if tincture of iodine is allowed to evaporate, the solution becomes more concentrated and may damage the flesh when applied to a wound.)

The following notes are a guide to first-aid treatment in the laboratory. (The teacher should wash his own hands thoroughly in soap and water before dealing with a cut or burn.)

Cuts—(*a*) Minor cuts and abrasions. (i) If clean, these should be swabbed with tincture of iodine on a pad of cotton wool, and then covered by a sterilized dressing, which may be held in position by adhesive tape or a bandage. (ii) Washing of the wound should be avoided unless it is dirty or contaminated by acid, etc. (Careful use of tweezers may be necessary to remove bits of glass.) A dirty cut may be swabbed with clean soapy water on a clean pad of cotton wool, then thoroughly dried and treated as in (i).

(*b*) Arterial bleeding. A doctor's attention is needed, and a tourniquet should not be applied without expert knowledge of procedure. A thick pad of gauze and/or cotton wool should be pressed over the wound. If the pad becomes soaked with blood it must not be removed but covered by another and larger one, and the pressure maintained. (Fainting is a common sequel even to minor injury, and should be treated as described below.)

Scalds—The affected part should be bathed gently with a warm saturated solution of sodium bicarbonate. It may then be treated as an ordinary dry burn.

Burns—Ordinary dry burns, even when small, are often painful and should be treated at once. Various methods are advised by the experts, and it is best for the teacher to get the recommendations of the doctor who will attend to any serious case at the school. The usual simple treatment is to cover the place with a sterilized pad of gauze or cotton wool soaked in sodium bicarbonate solution (to be replaced before it gets dry). The pad should then be covered by a sterile occlusive dressing (to keep out all 'germs'). Other possibilities are to cover the part liberally with: a 3 per cent. sulphanilamide cream (to be left for several days); *or* a gentian violet jelly, *or* a flavine jelly, which are sold in tubes for the purpose, with a daily and very careful change of the dressing. In any case it is most important to cover with the sterile dressing to exclude air. (It is best to sterilize dressings afresh when they are to be used—by heating in a steam or other oven—but they must *never* be applied hot.)

Larger burns require medical attention at the earliest possible moment, but should be covered immediately by sterile occlusive dressings, with or without the above-mentioned treatment. Every effort should be made to get the patient to hospital quickly.

Burns may produce shock, and when it occurs this must be treated.

In certain cases special procedure is necessary, and afterwards the injury must receive the same treatment as a dry burn:—

(*a*) Acid burns—must be washed immediately with large quantities of water (small amounts are dangerous) and then with sodium bicarbonate solution to neutralize any remaining traces of acid. In the case of a concentrated sulphuric acid burn it is better to give a liberal sprinkling with the solid bicarbonate. (The alkali, or its solution, must *never* be applied *before* washing on account of the heat of neutralization.)

(*b*) Alkali burns—must be washed with large quantities of water and then with a 1 per cent. solution of acetic acid, or with lemon-juice.

(*c*) Phosphorus burns—must be immersed in water and all traces of the substance washed away. The part should then be bathed in dilute silver nitrate solution. (Phosphorus burns are usually very severe.)

(*d*) Sodium and potassium burns—must be well washed with plenty of water *after* removal of the metal.

Eye injuries—Any injury to an eye must be dealt with by a doctor as soon as possible. A drop of castor oil should be put into the eye, which must then be covered by a pad of gauze or cotton wool and gently bandaged to exclude all light. The following preliminary treatment is necessary in some cases:—

(*a*) Acid in eye—The eye should be opened and closed under water, or it may be washed out by a slow stream of water from a wash-bottle. It should then be rinsed several times with lime-water or a 1 per cent. solution of sodium bicarbonate.

(*b*) Alkali in eye—The eye should be thoroughly washed with water as in (*a*) and then with a 1 per cent. solution of boric acid.

(*c*) Solid in eye—The eyelid may be turned back gently over a match-stick. Any obvious solid may be removed by a camel-hair brush dipped in glycerine.

Poisoning—In all cases a doctor should be consulted as soon as possible after the following treatment has been given:—

(A) Solids and liquids. If taken into the mouth they should be spat out at once and the mouth rinsed with much water, followed by a suitable mouth-wash (e.g. saturated sodium bicarbonate solution for acids, 1 per cent. acetic acid solution for alkalis).

When solid or liquid poisons are swallowed, the procedure should be:—

(*a*) For corrosive substances the patient should be given white-of-egg or milk, and rice-water or barley water. The patient should *not* be encouraged to vomit and should *not* be given emetics or purgatives. (i) In the case of acids, much water, followed by lime-water or milk of magnesia, should first be drunk. (ii) For alkalis, much water followed by dilute (1 per cent.) acetic acid, or lemon-juice, should be taken. (iii) Zinc compounds should first be treated by large quantities of dilute sodium carbonate solution.

(*b*) For non-corrosive poisons, an emetic should be given at once, e.g. a tablespoonful of common salt or a teaspoonful of mustard in a tumbler of warm water, to encourage vomiting. Then white-of-egg, rice-water, etc., should be taken.

(B) Gases. The patient must be taken into the fresh air at once, clothing must be loosened, and (if he is conscious) a stimulant such as hot coffee should be given. If the patient is unconscious, he should be treated as in the case of fainting. If necessary, artificial respiration must be applied. (To counteract chlorine or bromine fumes, the patient should smell ammonia and rinse the mouth and throat with sodium bicarbonate solution.)

Electric shock—The first thing is to switch off the current. If necessary the victim must be treated for burns and shock. He should be made to lie down flat and should be kept quiet and warm. In serious cases artificial respiration may be required.

Fainting—If a pupil feels or looks faint after an accident, his clothing should be loosened, and he should be made to sit in the open air with head between legs. Smelling salts should be applied, and a little cold water or stimulant (such as hot sweet tea) may be given, but only if he is quite conscious. If he is unconscious, he should be laid on his back with head on one side. Smelling salts should be applied and he should be kept very warm. On recovery he should be kept quiet for some time, and care should be taken to see that there is no relapse.

Shock—Symptoms and treatment are similar to those of a faint. Rest, quiet and warmth are essential.

APPENDIX A

Some Events, Names and Dates in the History of Science

A chart of this kind may be developed (and extended), in whole or in part, for any topic or series of topics in a science course. It may also be used to emphasize the 'international' nature of scientific work. The items selected here are merely examples: the teacher must make up his own tables to suit the syllabus covered by his class.

Event	*Approximate date*	*Some important names*
	B.C.	
Invention of the wheel	3000	
Metals used—chiefly as weapons	2000	(Beginning of Bronze Age)
Iron used in quantity	1000	(Beginning of Iron Age)
A first theory of matter	600	Thales (640–546)
Theory of 'Earth floating in space'	580	Anaximander (610–545)
Ideas of harmony (vibrating strings)	520	Pythagoras (560–500)
First theory of 'atoms'	470	Anaxagoras (*c.* 500–*c.* 428)
Development of theory of 'atoms'	440	Democritus (*c.* 460–370)
Ideas about 'Earth in motion'	400	Philolaus (? – ?)
Theory of the 'Four Elements'	350	Aristotle (384–322)
Development of systematic geometry	300	Euclid (? – ?)
Principles of density and levers	250	Archimedes (*c.* 287–212)
	A.D.	
Theories of astronomy and geography	140	Ptolemy (? – ?)
Animals dissected	160	Galen (124–199)
Study of reflection and pin-hole camera	1000	Al Hazen (965–1038)
Alchemy in Europe	1100	
Emphasis on experimental method	1250	Roger Bacon (1214–1292)
Discovery of magnetic compass	1300	'Gioja' (? – ?)
Invention of printing by moveable type	1450	Gutenberg (1398–1468)
Idea of 'Sun as centre of universe'	1500	Copernicus (1473–1543)
Study of human anatomy	1540	Vesalius (1514–1564)
Study of earth's magnetism	1570	Gilbert (1544–1603)
Accurate astronomical observations	1580	Tycho Brahe (1546–1601)
Work on the telescope, the pendulum and mechanics	1600	Galileo (1564–1642)
Study of planets—laws of motion	1600	Kepler (1571–1630)
Invention of thermometer	1602	
Study of gases	1610	Van Helmont (1577–1644)

Event	*Approximate date*	*Some important names*
	A.D.	
Invention of microscope	1610	
Study of blood circulation	1610	Harvey (1578–1657)
Study of vacua—mercury barometer	1630	Torricelli (1608–1647)
Use of air pumps	1650	Guericke (1602–1686)
Discovery of Pascal's law	1650	Pascal (1623–1662)
Statement of Boyle's law	1660	Boyle (1627–1691)
Work with the microscope	1660	Leeuwenhoek (1632–1723)
Discovery of Hooke's law	1670	Hooke (1635–1703)
Study of velocity of light	1674	Roemer (1644–1710)
Discoveries in astronomy	1690	Halley (1656–1742)
Steam engine (first piston engine)	1690	Newcomen (1663–1729)
Coal distilled	1690	Clayton (–)
Use of mercury thermometer	1714	Fahrenheit (1686–1736)
Study of positive and negative electricity	1740	Franklin (1706–1790)
Classification of plants	1740	Linnaeus (1707–1778)
Study of latent heat	1760	Black (1728–1799)
Determination of composition of water	1760	Cavendish (1731–1810)
Discovery of oxygen	1770	Priestley (1733–1804)
Development of steam engines	1770	Watt (1736–1819)
Work on electric cells	1770	Galvani (1737–1798)
Discovery of chlorine	1770	Scheele (1742–1786)
End of 'phlogiston theory'	1770	Lavoisier (1743–1794)
Ideas about organic evolution	1780	Lamarck (1744–1829)
First attempts at vaccination	1780	Jenner (1749–1823)
Discovery of planet Uranus	1781	Herschel (1738–1822)
First balloon ascent	1783	De Rozier (1756–1785)
Further discoveries in electricity	1800	Volta (1745–1827)
Statement of atomic theory	1800	Dalton (1766–1844)
Statement of Ampère's rule	1800	Ampère (1775–1836)
Production of first locomotive	1804	
Study of combining volumes of gases	1810	Gay Lussac (1778–1850)
Work in electro-chemistry	1810	Davy (1778–1829)
Further electrical discoveries	1810	Ohm (1781–1845)
Beginnings of photography	1814	Daguerre (1789–1851)
Invention of stethoscope	1816	Laennec (1781–1826)
Study of electro-magnetic induction	1820	Faraday (1791–1867)
Invention of electric bell	1831	Henry (1797–1878)
Study of mechanical equivalent of heat	1840	Joule (1818–1889)
Theory of evolution announced	1840	Darwin (1809–1882)
Discovery of planet Neptune	1846	Adams, Leverrier, Galle
Study of micro-organisms	1860	Pasteur (1822–1895)
Statement of electro-magnetic theory	1860	Maxwell (1831–1879)
Study of heredity	1860	Mendel (1822–1882)
Dynamite produced	1869	Nobel (1833–1896)

Event	*Approximate date*	*Some important names*
	A.D.	
Elements classified in periodic table	1869	Mendeléeff (1834–1907)
First typewriter produced	1873	
Invention of telephone (commercial)	1876	Bell (1847–1928)
First gramophone made	1877	Edison (1847–1931)
Incandescent electric lamp invented	1878	Edison, Swan
First automobile produced	1879	
Detection of wireless waves	1887	Hertz (1857–1894)
First motion picture shown	1893	Edison
Discovery of X-rays	1895	Röntgen (1845–1923)
Discovery of radioactivity	1896	Becquerel (1852–1908)
Existence of electrons shown	1897	J. J. Thomson (1856–1940)
Radium isolated	1898	The Curies (1859–1906, 1867–1934)
First transatlantic radio signal	1901	Marconi (1874–1937)
First aeroplane flight	1903	The Wright brothers
Theory of relativity stated	1905	Einstein (1879–1955)
First synthetic resin produced	1906	Baekeland (1863–1944)
Study of conditioned reflexes	1910	Pavlov (1849–1936)
Discovery of atomic structure	1911	Rutherford (1871–1937)
Investigation of vitamins	1912	Hopkins (1861–)
Study of crystal structure	1915	Bragg (1862–1942)
Transmutation of an element	1919	Rutherford
Discovery of penicillin	1928	Fleming
Radioactivity produced artificially	1934	Curie and Joliot
Study of atomic fission	1938	Hahn and Strassmann
Explosion of first 'atom bomb'	1945	

Note.—It should be mentioned that such a list indicates progress in mechanical skills as well as the growth of scientific knowledge.

The teacher should make sure that pupils understand:

(*a*) The reason for describing the dates as *approximate*. It is difficult to decide upon *exact* dates because: (i) the information is sometimes lacking; (ii) a discovery may remain unnoticed, or the records may not be published, for many years; (iii) discoveries and inventions are often the result of many years of investigation; (iv) many people in different countries often work along similar lines during the same period.

(*b*) That under 'important names' it is possible to give only one or two of the most outstanding. It must be remembered that in most cases many other workers deserve inclusion. In some cases no names are given because the actual origins may be obscure, or development has been gradual and carried out by several people in various places.

APPENDIX B

Stars and Planets

The columns of table (i) give the following data:—

(*a*) The names of the brightest stars in descending order of brightness.

(*b*) The name of the constellation in which the star appears. (The *signs of the zodiac* are printed in capitals.)

(*c*) The month when the star reaches its highest point above the horizon at about 8 p.m. local time.

(*d*) The month when the star reaches its highest point above the horizon at about 10 p.m. local time.

(*e*) The angle between the elevation of the star, when it is at its highest in the sky, and the elevation of the sun at *noon*, local time, during the month given in column (*c*). For example, to find Capella during January at 8 p.m., the observer should first look toward the place where the sun appeared to be at *noon* by local time, and then turn his gaze *northward* through 70° (approximately).

Note—α-Centauri and β-Centauri are the 'pointers' for the Southern Cross. α-Centauri is the farthest from the Cross. It is the nearest bright star to the Earth, which its light takes about four years to reach.

Of the four bright stars which outline the Southern Cross, α-Crucis is the farthest south, and β-Crucis the farthest east.

In the HEAVENLY TWINS, Castor is to the north of Pollux.

The columns of table (ii) show the names of the planets, their distances from the sun, their diameters, and the times taken for their orbits.

The positions of the planets relative to the stars vary during the course of the year, and the brightness of each is also variable. (The positions of the planets in the sky at a particular time must be found from an appropriate almanack.)—See notes on page 288.

(*i*) *Stars in descending order of brightness*

Star	*Constellation*	*Time of northing or southing*		*N. or S. of sun's position at noon*
		8 *p.m.* *Month*	10 *p.m.* *Month*	
(*a*)	(*b*)	(*c*)	(*d*)	(*e*)
Sirius	Big Dog	February	January	10° S.
Canopus	Ship Argo	February	January	40° S.
α-Centauri	Centaur	June	May	80° S.
Vega	Lyre	August	July	30° N.
Capella	Charioteer	January	December	70° N.
Arcturus	Herdsman	June	May	0°
Rigel	Orion	January	December	10° N.
Procyon	Little Dog	February	January	20° N.
Achernar	River Eridanus	December	November	30° S.
β-Centauri	Centaur	June	May	80° S.
Altair	Eagle	September	August	10° N.
Betelgeuse	Orion	February	January	20° N.
α-Crucis	Southern Cross	May	April	80° S.
Aldebaran	BULL	January	December	40° N.
Pollux	HEAVENLY TWINS	March	February	30° N.
Spica	VIRGIN	May	April	30° S.
Antares	SCORPION	July	June	50° S.
Formalhaut	Southern Fish	October	September	20° S.
Deneb	Swan	September	August	40° N.
Regulus	LION	April	March	0°
β-Crucis	Southern Cross	May	April	80° S.
Castor	HEAVENLY TWINS	March	February	30° N.

(*ii*) *Planets in increasing order of distance from the sun*

Planet	*Distance from sun (millions of miles)*	*Diameter (thousands of miles)*	*Time taken to complete orbit (years)*
Mercury	36	3·2	0·24
Venus	67	7·85	0·62
Earth	93	7·9	1·00
Mars	142	4·25	1·88
Jupiter	483	89	11·9
Saturn	887	75	29·5
Uranus	1785	31	84
Neptune	2797	33	165
Pluto	3675	4	248

Note—Mercury is only visible for not more than half an hour either before sunrise or after sunset.

Venus is visible for not more than three hours either before sunrise or after sunset.

Mars, *Jupiter* and *Saturn* are often very conspicuous objects in the sky.

Uranus only, of the remainder, is visible to the naked eye, and has the appearance of a faint star.

(*iii*) *Latitudes and dates when the sun is directly overhead at noon*

Latitude	*Dates*		*Latitude*	*Dates*	
23·5° N. .	June 21 [1]	June 21 [1]	23·5° S. .	Dec. 22 [2]	Dec. 22 [2]
23° N. .	July 3	10	23° S. .	Jan. 2	11
22° N. .	12	1	22° S. .	10	3
21° N. .	19	May 26	21° S. .	16	Nov. 27
20° N. .	24	21	20° S. .	21	22
19° N. .	29	16	19° S. .	25	18
18° N. .	Aug. 2	12	18° S. .	29	14
17° N. .	6	8	17° S. .	Feb. 2	10
16° N. .	9	5	16° S. .	5	7
15° N. .	12	1	15° S. .	9	3
14° N. .	16	Apr. 28	14° S. .	12	Oct. 31
13° N. .	19	25	13° S. .	15	28
12° N. .	22	22	12° S. .	17	25
11° N. .	25	19	11° S. .	20	22
10° N. .	28	16	10° S. .	23	20
9° N. .	31	13	9° S. .	26	17
8° N. .	Sept. 2	11	8° S. .	28	14
7° N. .	5	8	7° S. .	Mar. 3	12
6° N. .	8	5	6° S. .	6	9
5° N. .	10	3	5° S. .	8	6
4° N. .	13	Mar. 31	4° S. .	11	4
3° N. .	16	29	3° S. .	13	1
2° N. .	18	26	2° S. .	16	Sept. 29
1° N. .	21	23	1° S. .	18	26
Equator .	23 [4]	21 [3]	Equator	21 [3]	23 [4]

[1] Summer solstice.

[2] Winter solstice.

[3] Spring equinox.

[4] Autumn equinox.

APPENDIX C

A Typical Skeleton Syllabus

A 4-year course in General Science. (Parts in parentheses are suitable for inclusion in a fifth year, if the pupil is not already specializing in one or more branches of science.)

The sections from 'PLANTS' onwards must be fitted into the scheme, when most suitable and appropriate, according to times and seasons.

WATER

Local sources, rivers, springs, wells, artesian borings; prevention of contamination.
Purification of large quantities, filtration of town supplies; (chlorination).
Purification of small quantities, filtration, boiling, distillation.
Aqueous solutions, crystallization and purification of soluble salts; water of crystallization, hydrated and anhydrous salts; efflorescence and deliquescence; desiccators and similar devices.
A necessity of all life, transpiration in plants.
Evaporation, associated with cooling; cooling devices in a hot climate; water in the atmosphere; wet and dry climates; sweating.
Plants adapted for dry climates; (change of vapour pressure with change of temperature).

AIR

Composition, active and inactive constituents; (rare gases).
Breathing, respiration in plants and animals.
Burning, common products from naturally occurring materials: (i) water, (ii) carbon dioxide.
Rusting of iron, necessary conditions, prevention.
Active constituent; isolation from mercuric oxide and other sources; properties. Manganese dioxide as example of a catalyst.
Common oxides, acidic and basic oxides.
Ventilation.
The flame, e.g. candle and Bunsen flames.

TUTE OF EDUCATION FOR
Dept. of Extension
SERVICE.

Fire extinguishers, prevention of fire.
Solution in water, removal; biological importance.
Adaptation to environment; fish, amphibians.

CARBON DIOXIDE

Product of breathing, presence shows that plants and animals contain carbon.
Photosynthesis during sunlight, but respiration a continuous process; carbon cycle.
Carbonates, produced by living creatures, foraminifera, coral; a source of carbon dioxide.
Isolation, properties and uses.
Part played in cooking; baking powder, yeast, ferments in local use.
Chalk or limestone, lime, lime-water and their relationships.

HEAT

Sources.
Melting, difference from solution.
Transference: (*a*) *Convection:* (i) in gases; ventilation, rain and thunderstorms;
(ii) in liquids; ocean currents;
(*b*) *Conduction:* insulators and conductors; clothes, vacuum flask;
(*c*) *Radiation:* effect of surfaces, reflection of radiant heat.
Measurements of temperature; thermometers, thermometer scales; thermostats.
Effects: (*a*) *Expansion* of solids, compensating devices;
of liquids, comparison of liquids used in thermometers;
of gases, Charles' law; absolute zero.
(*b*) *Change of state;* melting and boiling points, and methods of determination.
Measurement; simple comparisons of heat capacity, specific heat, latent heat.
Humidity; wet and dry bulb thermometers; the cryophorus.

THE NIGHT SKY

Phases of the moon.
Planets and stars.
Apparent movement of the stars.
Meteors and comets.
Galaxies and nebulae.
(Fixing the position of a star.)

MECHANICS

Levers, pulleys, gears, cranks, etc., with simple calculations on mechanical advantage, velocity ratio and efficiency.
Friction; practical effects, means for increase and reduction; (laws of).
Structural importance of triangles.
Straight line movement and acceleration.
Force; various kinds, measurement, Hooke's law.
Work and power.
Energy; storage; kinetic and potential, the characteristics of a pendulum;
conservation and transformation of energy (mechanical equivalent of heat).
Engines; water-wheel, windmill, steam engine, four-stroke petrol engine, turbine, jet, jet-turbo ; (thermal efficiency).
Pumps and valves; sprays and jets.

SOUND

Speed; need for material medium.
Frequency and wave-length, their measurement.
Audibility, limits; echoes, echo-sounding.
Vibrations, transverse and longitudinal ; (sine curve, resultant of two simple harmonic motions, beats, interference).
Music, notes and noise, conditions of harmony.
Musical instruments.
Resonance.
(Moving source and change of pitch, Doppler effect.)

LIGHT

Straight line propagation; shadows, point source and large source; eclipses; pin-hole camera.

Reflection at plane surfaces, comparison with radiant heat; position, nature and size of image.

Reflection at concave and convex surfaces; position, nature and size of image.

Refraction at plane surfaces; total internal reflection, examples by construction (and by calculation; Snell's law).

Convex and concave lenses; correction of sight; (position, nature and size of image).

The camera and the eye.

Reflecting prisms; other optical apparatus (microscope, telescope).

Colour, spectrum colours, association with wave-length, coloured bodies in coloured light; primary colours and colour blindness; addition of colours (subtraction of colours, colour printing and colour photography).

(Association of wave-length with chemical elements, spectrum analysis, composition and speed of stars.)

WATER AS A COMPOUND

Effect on metals, activity series.

Hydrogen, isolation and properties, reduction of oxides.

Elements, compounds and mixtures; atoms and molecules—comparison of water and air in this respect.

Physical and chemical changes, comparison.

Law of constant composition; simple formulae (and calculations).

Law of multiple proportions.

(Evidence for the existence of atoms and molecules.)

ACIDS AND BASES

Metals and non-metals: convenient categories.

Salts, preparation and purification by various methods.

Solubility; construction of solubility curve.

Strong and weak acids and bases.

Acids from salts; carbon dioxide—revision; hydrochloric acid, isolation and properties; nitric acid, isolation and properties; explosives.

Alkalis from salts; ammonia, isolation and properties; nitrogen cycle.

Acidic and basic salts.

Chlorine, isolation, properties and uses.

DENSITY

Weight per unit volume.

Floating and sinking; hydrometers.

Archimedes' principle, and upward lift; balloons and submarines.

PRESSURE

Weight per unit area.

Hydraulic presses and brakes, etc.

Measurement; manometer, head of water, Bourdon gauge.

Pascal's experiment.

Effects: on *gases*—Boyle's law (calculations involving N.T.P.);
on *ice*—regelation, movement of glaciers;
on *boiling points*—pressure cookers, sterilizers; (distillation under reduced pressure, distillation of crude oil, evaporated milk).

Atmospheric pressure; measuring devices and records; weather in more detail; clouds.

Refrigerators.

CARBON AND ITS COMPOUNDS

The element and its allotropes.

Facility to form complex compounds, e.g. paraffins.

Starch, sugar, alcohol, enzyme action; the effects of alcohol on the human body.

Oils and fats, saponification.

Soap and glycerol; local manufacture of soap.

(Colloidal solutions, smoke, etc.)

Hard and soft water—especially for schools in hard water areas.

Carbon monoxide; characteristic flame; (isolation).

SULPHUR

The element and its allotropes.
(Sulphuric acid manufacture.)
(Sulphur dioxide.)

ELECTRICITY AND MAGNETISM

Current, sources; generation and storage; primary and secondary cells.
The circuit—the fundamental idea:—
    something pushed—the current,
    something to push it—the voltage,
    something to carry it—the conductor, offering a resistance.
Ohm's law, conductors and cells in series and parallel.
Insulators and conductors; variable and fixed resistances.
Effects: heating, chemical, magnetic.
Electrolysis (laws); electroplating; (secondary reactions, preparation of chlorine and caustic soda).
Electro-magnetism, simple motors and dynamos.
Measuring instruments, alternating and direct current; their position in the circuit; (all-test instruments, bobbins and shunts).
Common appliances; examination of house wiring system; switches, fuses, etc.; earthing; arcs, electric welding.
Watts, kilowatts, kilowatt-hours or units; calculation of consumption and cost.
Induction coil, transformers and power transmission.
Telegraph and telephone; microphone.
Earth's magnetism.
Magnets; making and destruction of magnetism.
Electro-magnets and their uses; electric bell.
(Radio; crystal, diode, triode, amplification, rectification.)
(Electro-magnetic waves, the full scale.)

STRUCTURE OF THE ATOM

(Radioactivity, periodic table, fission.)

WORLD'S MINERAL WEALTH

Oil and its products.

Metals, from ores: by reduction, iron, (copper); by electrolysis, aluminium, (sodium).

Alloys, ferrous and non-ferrous; properties and uses; (manufacture of steel).

PLANTS

Germination of seeds, conditions of germination.

Responses to stimuli: light, water, gravity.

Function of parts: root, stem, leaf, flower.

Fertilization, seed dispersal.

Food manufacture; photosynthesis.

Food storage and transfer.

Propagation, methods of: budding, layering; seeds, bulbs, suckers, corms, runners, root and stem tubers, etc.

Cycles of growth and decay.

Carbon cycle.

Nitrogen cycle; ammonia, nitric acid, nitrates; bacteria; crop rotation.

Simple classification.

SOIL

Constituents and types; humus; manures, natural and artificial.

Erosion, causes and prevention.

CAPILLARITY

Surface tension, drops, bubbles; action of soap and other detergents.

OSMOSIS

Movement of fluids through membranes in living organisms.

DIFFUSION

In gases and liquids.

INSECTS, etc.

A selection from: flies, beetles, moths or butterflies, bees or wasps, ants, termites, spiders.

Study of structure, metamorphoses; food, breathing, reproduction, social organization.

ADAPTATION TO ENVIRONMENT

Fish, amphibians, birds, mammals.

ANIMALS, INCLUDING MAN

Main skeleton; work of muscles, attachment of arm and leg muscles.

Control mechanisms, responses to stimuli.

Blood, as oxygen carrier; systemic and pulmonary circulations; structure of veins and arteries; first-aid.

Food, main constituents, tests for; calorific value; vitamins.

Digestion; enzymes; tests to show main processes.

Excretion; breath; sweat; kidneys and bladder; large intestine and anus.

Blood, as carrier of nourishment and waste; other functions.

Blood—summary of functions.

Reproduction; heredity, simple genetics.

Simple classification, tracing common features through various phyla; development of digestive and nerve systems from simple to complex examples.

Evolution, evidence for; classification, distribution, vestigial remains, fossils.

THE CELL

Living units, from which organisms are built up.

MICROSCOPIC ORGANISMS

A one-celled animal, a rather more complex animal; a microscopic plant, a yeast, a mould.

BACTERIA and VIRUSES

In health and disease.
Immunization, vaccination.
Antiseptics and antibiotics.
Food preservation.
Social hygiene: sanitation, disposal of refuse.

LOCAL DISEASES

Causes, prevention and simple treatment.
Malaria, hookworm, sleeping sickness, beri-beri, etc.

NATURE ACHIEVES A BALANCE

Man's interference with nature; agriculture as planned co-operation with nature.
(Biological control of pests.)

APPENDIX D

I. Some further examples of

Instruction Cards for Pupils' Experiments

(see page 103)

(1) *The density of a substance 'lighter' than water*

EXPT. 8—To find the density of a bottle cork

Apparatus: Cork, glass measuring cylinder.

Method: Partly fill cylinder with water.
Read water level.
Let the cork float in the water.
Read water level.
Push cork just under the water with a long pointed instrument (e.g. compass).
Read water level while cork is submerged.
Calculate WEIGHT of cork from displacement while floating.
Calculate VOLUME of cork from total displacement when submerged.
Calculate DENSITY of cork.

In note-book write number and title of expt.
Leave ten lines blank and then record measurements and calculations thus:

First water level =
Water level, cork floating =
Water level, cork submerged =

∴ Volume displaced when floating =
∴ WEIGHT of cork =
Volume displaced when submerged =
∴ VOLUME of cork =
∴ Density of cork =

In space left blank write an exact description, in order, of how the experiment was carried out.

(2) *Observation of a biological specimen*

EXPT. 26—To examine the wing of a bat

Provided: A dead bat.

In note-book, write number and title of experiment and then write the answers to the following questions:

(*a*) What is the length of the bat from head to tail?
(*b*) What is the length of each wing when fully stretched out?
(*c*) How many 'fingers' are used to keep the wing in shape?
(*d*) Is there a 'fifth finger'? if so, what is its shape?
(*e*) For what purpose might this 'fifth finger' be used?
(*f*) Are there any feathers on the wing?
(*g*) What does the wing feel like to touch? (Describe it in a sentence.)
(*h*) Are the wings attached to the body of the bat?
(*j*) Are the hind legs attached to the wings?
(*k*) Is there anything else to notice about the wings?

Draw the wing as it appears when stretched out.

(3) *A series of experiments on saliva*

(see pages 105–6)

In the four typical instruction cards which follow, the parentheses indicate where the pupil should record results, but here some representative observations and conclusions are included:—

(*a*) Does saliva react with starch?

EXPT. I—To examine the action of saliva on starch

Provided: Starch solution, iodine solution, test-tubes, watch-glasses.

Prepare: Saliva solution according to instructions.

Method: Place a drop of iodine solution in each of eight watch-glasses.

Mix equal quantities of starch and saliva solutions in a test-tube; note the time. Using a clean glass tube, extract a drop of the mixture and place in watch-glass 1. Note any colour change. After half a minute extract another drop of the mixture, using a clean glass tube, and place in watch-glass 2. Note any colour change. After one minute from the time of mixing, and with a clean tube, extract another drop of the mixture and place in watch-glass 3. Note any colour change. Repeat the process, each time with a clean tube, 2 min., 5 min., 10 min., 20 min., 30 min. after mixing, in the other watch-glasses.

Control experiment:—Test the original starch solution at the beginning of the experiments, and after it has been standing for 30 minutes unmixed with saliva. (Place a sample in each of two other watch-glasses containing a drop of iodine solution, and note any colour changes.)

Write the number and title of the experiment in note-book, describe it and record the results in a table thus:

Saliva acting for:	*Colour with iodine*	*Conclusion*
0 min.	(blue)	(starch present)
½ ,,	(blue)	(starch present)
1 ,,	( )	( )
2 ,,	( )	( )
5 ,,	( )	( )
10 ,,	( )	( )
20 ,,	( )	( )
30 ,,	(brownish)	(starch absent)

Control expt. Starch solution and iodine

At beginning (blue coloration)
Conclusion (starch present)

Starch solution and iodine
After 30 min. (blue coloration)
Conclusion (starch unchanged)

General conclusion: (Saliva causes starch to change into something else) (*b*) Does boiled saliva react with starch?

EXPT. 2—To examine the action of boiled saliva on starch

Provided: Starch solution, iodine solution, test-tubes, watch-glasses.

Prepare: Saliva solution according to instructions.

Method: Boil a solution of saliva gently for ten minutes.
Place a drop of iodine solution in each of eight watch-glasses.
Mix equal quantities of starch and saliva solutions in a test-tube; and note the time.
Using a clean glass tube, extract a drop of the mixture and place in watch-glass 1. Note any colour change.
After half a minute extract, using a clean glass tube, a drop of the mixture and place in watch-glass 2. Note any colour change.
After one minute from the time of mixing, using a clean tube, extract another drop of the mixture and put in watch-glass 3. Note any colour change.
Repeat the process, each time with a clean tube, 2 min., 5 min., 10 min., 20 min. and 30 min. after mixing, in the other watch-glasses.

Write the number and title of the experiment in note-book, describe it and record the results in a table thus:

Boiled saliva acting for:	*Colour with iodine*	*Conclusion*
0 min.	(blue)	(starch present)
½ ,,	(blue)	(starch present)
1 ,,	( )	( )
2 ,,	( )	( )
5 ,,	( )	( )
10 ,,	( )	( )
20 ,,	( )	( )
30 ,,	(blue)	(starch present)

Conclusion: (Boiled saliva has no effect on starch) (*c*) Does saliva act best in acid or alkaline solution?

EXPT. 3—To examine the action of saliva when the solution is (a) acid, (*b*) alkaline

Provided: Starch solution, iodine solution, test-tubes, watch-glasses.

Prepare: Saliva solution according to instructions.

A test: Test saliva by moistening a piece of red litmus in the mouth. (It will be found that saliva is usually alkaline to litmus.)

Method: Take a test-tube one-third full of saliva solution and add about 2 drops of dilute hydrochloric acid, so that the solution gives a faint acid reaction with blue litmus.

Take a test-tube one third full of saliva solution and add about 2 drops of caustic soda so that the solution gives a definite blue colour to red litmus.

Place a drop of iodine solution in each of eight watch-glasses.

Mix equal quantities of starch and acid saliva solutions in a test-tube; note the time. After 1 minute extract a drop of the mixture, with a clean glass tube, and place in watch-glass 1. Note any colour change. Repeat, using a clean tube, after 5, 10 and 30 minutes from the time of mixing. Place samples in watch-glass 2, 3 and 4, respectively.

Repeat the four tests, at the same intervals, this time using a mixture of starch and alkaline saliva solutions.

Write the number and title of the experiment in notebook, describe the experiment, and enter your observations in a table thus:

(a)			(*b*)		
Starch and acid saliva, after:	*Colour with iodine*	*Conclusion*	*Starch and alkaline saliva, after:*	*Colour with iodine*	*Conclusion*
1 min.	(blue)	(starch present)	1 min.	(blue)	(starch present)
5 „	( )	( )	5 „	( )	( )
10 „	( )	( )	10 „	( )	( )
30 „	(blue)	(starch present)	30 „	(brown)	(starch absent)

Conclusion: (Saliva remains active in the presence of alkali but loses its activity in the presence of acid) (*d*) At what temperature is starch most readily affected by saliva?

EXPT. 4—To determine the temperature at which saliva acts most quickly on starch

Provided: Starch solution, iodine solution, test-tubes, watch-glasses, thermometer, beakers, ice.

Prepare: Saliva solution according to instructions.

Method: Place a drop of iodine solution in each of five watch-glasses.
Cool two test-tubes, containing respectively saliva and starch solutions, by standing them in a beaker of water kept at 5° C. by the addition of ice. When both solutions are at 5° C., mix them, keeping them at the same temperature. Extract a drop of the mixture with a clean glass tube 1 minute after mixing, and place in watch-glass 1. Note any colour change.
Extract another drop of the mixture with a clean glass tube 5 minutes after mixing, and place in watch-glass 2. Note any colour change.
Repeat the process, adding samples extracted after 10 min., 20 min. and 30 min. to watch-glasses 3, 4 and 5 respectively.

Repeat the five tests, this time keeping the solutions before and after mixing at 20° C.

Similarly repeat the five tests keeping the solutions before and after mixing at 30° C.

Repeat at temperatures of: 40° C., 60° C., 80° C.

Write the number and title of the experiment in note-book, describe it, and record results and conclusions in a table thus:

Saliva acting for	Temperature					
	5° C.		20° C.		30° C.	
	Colour	*Conclusion*	*Colour*	*Conclusion*	*Colour*	*Conclusion*
1 min.	(blue)	(starch present)	(blue)	(starch present)	(blue)	(starch present)
5 ,,	(blue)	( )	(blue)	( )	(blue)	( )
10 ,,	(blue)	( )	( )	( )	(purple)	( )
20 ,,	(purple)	( )	( )	( )	(brown)	( )
30 ,,	(purple)	( )	( )	( )	(brown)	( )

	Temperature					
	40° C.		60° C.		80° C.	
1 min.	(blue)	( )	( )	( )	(blue)	( )
5 ,,	(purple)	( )	( )	( )	(blue)	( )
10 ,,	(brown)	( )	( )	( )	(blue)	( )
20 ,,	(brown)	( )	( )	( )	(blue)	( )
30 ,,	(brown)	( )	(purple)	( )	(blue)	( )

Conclusion: (Saliva acts most quickly on starch at about 40° C.)

II. Some further examples of Science 'Quiz' Cards and Answer Cards

(see pages 134 and 172–3)

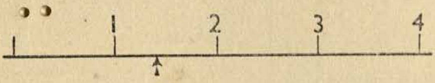
'QUIZ' CARD 2	**Answers to 'Quiz' 2**
1. What is the speed of sound in air?	1100 ft. per sec.
2. An apparatus with a name ending in '*-scope*' shows something; an apparatus with a name ending in '*-meter*' measures something: e.g. compare the names 'thermoscope' and 'thermometer'. Name other similar pairs.	Microscope Micrometer *or* Spectroscope Spectrometer
3. Name two organs of the body mainly concerned with purifying the blood.	Liver Kidneys
4. What element most closely resembles sodium?	Potassium
5. What colour is the outside arc of a rainbow?	Red
Give the initial letters of the seven colours of the rainbow in order.	V.I.B.G.Y.O.R
6. What instrument is used to measure the length of a curved line?	Opisometer
7. State the formula used to represent Ohm's law.	$V=CR$, or $\frac{V}{C}=R$, or $\frac{V}{R}=C$
8. At what temperature does ether boil?	35° C.
9. Name the three parts of vascular bundles in plant stems.	Wood, cambium, bast
10. What name is given to a wheel which turns about a point not its centre?	Cam, or eccentric

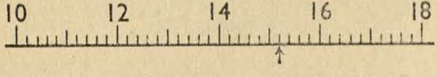
'QUIZ' CARD 3	**Answers to 'Quiz' 3**
1. What name is given to the place where a collection of dried plants is kept?	Herbarium
2. How many petals has a (named local) flower?	.....
3. Is saliva acid or alkaline?	Alkaline
4. What name is given to the instrument that measures the speed of the wind?	Anemometer
5. Are bats blind?	No
6. What kind of naturally occurring water is likely to be the purest?	Rain water
7. Which two colours make (*a*) purple? (*b*) peacock?	Red and blue Green and blue
8. What are the limits of human audibility?	20 to 20,000 vibrations per second approximately
9. What instrument is used to measure the inside or outside diameters of tubes?	Callipers
10. Name the long-handled sharp knife used in making dissections.	Scalpel

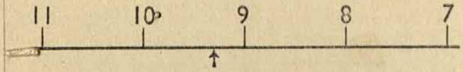
'QUIZ' CARD 4	**Answers to 'Quiz' 4**
1. What instrument measures the radius of curvature of a spherical object?	Spherometer
2. Who first worked out calculations about levers?	Archimedes
3. What single word describes a common property of cotton, rubber, sulphur, wood and silk?	Insulator
4. What are the three main constituents of food?	Carbohydrates, fats, proteins
5. Into what class do biologists put dormice, rats, mice, squirrels?	Rodents
6. How many seed leaves has maize?	One
7. What is the chemical formula for sodium bicarbonate?	$NaHCO_3$
8. From what is bleaching powder made?	Slaked lime and chlorine
9. Which are the highest cloud formations?	Cirrus
10. How are watts, amperes and volts connected?	$W = CV$

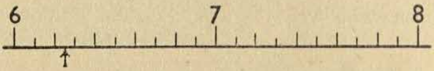
'QUIZ' CARD 5

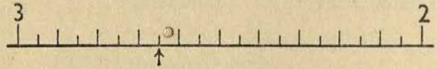
To what numerical values do the arrows point on the following scales?

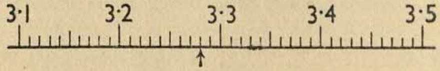


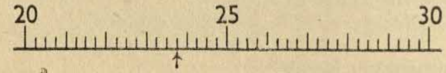


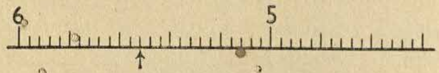


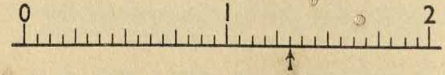


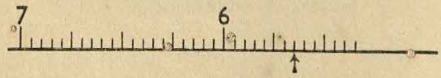












Answers must be given in decimals.

Answers to 'Quiz' 5

1·4

15·2

9·3

6·25

2·65

3·28

23·75

5·52

1·3125

5·65

APPENDIX E

Materials for the Teaching of General Science

The following list has been divided into two parts:
Part I—items of apparatus
Part II—chemicals, including stains, reagents, etc.

In compiling the list the following assumptions have been made:
(*a*) that there will be two parallel classes each taking a four-year course in General Science;
(*b*) that the time which may elapse between ordering and receiving apparatus and chemicals may amount to six months or even more;
(*c*) that each class will contain from 24 to 30 pupils;
(*d*) that pupils will usually work in pairs;
(*e*) that all the pairs in each class will not necessarily be doing the same experiment at the same time.

Where the above assumptions do not apply, the necessary adjustments in the quantities suggested must be made.

Note—When ordering apparatus which is to be connected to the local electric mains, it is necessary to state the characteristics of the supply: these are (i) the voltage; (ii) whether A.C. (alternating current) or D.C. (direct current); (iii)—if A.C.—the number of cycles. This information is usually stamped upon the front of the electric meter, which is near the mains switch controlling the supply.

(Every science master should know the position of this mains switch so that the supply can be turned off at once in case of fire or other emergency.)

PART I—LIST OF APPARATUS

Apparatus is expensive to buy, especially from overseas sources. In order to draw attention to economies and the value of home-made articles, many items have been marked as follows:—

*—Useful but not essential
JG—Obtainable as junk from garages
JE—Obtainable as junk from an electricity supply station
L—Probably obtainable locally
ML—Can be made locally

*	1	Aerator for aquarium [1]
	1	All test instrument: with bobbins and shunts to cover range from 0·150 amps. to 30 amps., and from 0·150 volts to 30 volts
	3	Ammeters, bench type, 0–2 amps., moving coil (for D.C.), centre zero
	3	,, , ,, ,, , 0–5 amps., moving coil (for D.C.), centre zero
	1	,, , ,, ,, , 0–2 amps., moving iron (for A.C.)
	1	,, , ,, ,, , 0–10 amps., ,, ,, (,, ,,)
	1	,, , ,, ,, , 500–0–500 milliamps., moving coil (for D.C.)
JG		Armatures
L	24	Asbestos-cement squares, 6″ × 6″
L	6	,, ,, ,, , 12″ × 12″
	6	Aspirators, 10-litre
*	1	Atomic models, set
	1	Balances, Beranger, 2 Kg.
*	1	,, , Chemical, analytical, 100 g., with rider and weights
	1	,, , ,, , ordinary, 200 g., with rider, weights, and fractional weights
	12	,, , ,, , ordinary, 250 g., with riders and weights (no fractions)
	1	,, , Compression type, dial scale, 5 Kg.
	12	,, , spring, 100 g.
	12	,, , ,, , 1 Kg.
	6	,, , ,, , 4 lb. × $\frac{1}{10}$ lb.
	6	,, , ,, , 2 lb. × $\frac{1}{10}$ lb.
JG	6	Ball bearings, steel, of each size: ¼″, ½″, 1″ diam.
	1	Ball and ring (expansion apparatus)

---

[1] Electrical aerator, if mains electricity is available; the voltage, etc., must then be stated.

	6	Balloons, toy
*	1	Bar and gauge (expansion apparatus)
*	1	Bar breaker (expansion apparatus)
	1	Barometer, aneroid
	1	,, , Fortin, standard mercury
		Barometer tubes—see 'Tubes'
L	6	Bars, soft iron, 8″
	3	Basins, evaporating, glass, 200 ml.
	24	,, , ,, , porcelain, 50 ml.
	24	,, , ,, , ,, , 100 ml.
	6	,, , ,, , ,, , 250 ml.
L	12	Baths, sand
*	6	,, , water, copper, with rings, 18 cm.
*	1	,, , ,, , constant level
*	1	,, , ,, , ,, ,, , electric[1]
*	6	Beakers, aluminium, 400 ml.
	24	,, , glass, 100 ml., squat, with spout
	24	,, , ,, , 250 ml., ,, , ,, ,,
	24	,, , ,, , 500 ml., ,, , ,, ,,
	12	,, , ,, , 600 ml., ,, , ,, ,,
	12	,, , ,, , 1000 ml., ,, , ,, ,,
	24	,, , ,, , 250 ml., tall (no spout)
	24	,, , ,, , 500 ml., ,, ,, ,,
	6	,, , ,, , 600 ml., ,, ,, ,,
	6	,, , ,, , 1000 ml., ,, ,, ,,
ML	12	Beehive shelves,[2] earthenware, 10 cm.
	2	,, ,, , glass, 10 cm.
	2	Bell-jars, ground glass stopper, 15 cm.
	2	,, ,, , ,, ,, ,, , 22 cm.
	3	,, ,, , glass knob, no stopper, 22 cm.
	2	Bells, electric, small
	1	Bi-metallic strip
*	1	Binoculars, prismatic

Blackboard accessories:

	2	Blackboard Compasses

---

[1] The voltage must be stated.

[2] Easily made from tins.

2	Blackboard Protractors	
2	,, Rulers	
1	,, Set-squares (45°)	
1	,, ,, ,, (30°, 60°)	
2	,, T-squares	
	Blowpipe—see '*Gas burners*'	
12	Blowpipes, mouth	
6	Boats, porcelain, 7·5 cm. × 1 cm.	
	Bosses—see ' Stands, iron, retort'	
4	Bottles, Canada balsam or ether	
36	,, , dropping	
* 4	,, , gas washing	
* 4	,, , iron, for expansion experiments	
50	,, , reagent, ground-in stopper, narrow neck for liquids	100 ml.
100	,, , ,, , ground-in stopper, narrow neck for liquids	250 ml.
50	,, , ,, , ground-in stopper, narrow neck for liquids	500 ml.
6	,, , ,, , ground-in stopper, narrow neck for liquids	1000 ml.
24	,, , ,, , ground-in stopper, wide neck for solids	100 ml.
24	,, , ,, , ground-in stopper, wide neck for solids	250 ml.
12	,, , ,, , ground-in stopper, wide neck for solids	500 ml.
6	,, , ,, , ground-in stopper, wide neck for solids	1000 ml.
36	,, , ,, , ordinary narrow neck for liquids, unstoppered	100 ml.
36	,, , ,, , ordinary narrow neck for liquids, unstoppered	250 ml.
12	,, , ,, , ordinary narrow neck for liquids, unstoppered	500 ml.
24	,, , ,, , ordinary wide neck for solids, unstoppered,	100 ml.

L	36	Bottles, reagent, ordinary wide neck for solids, unstoppered	250 ml.[1]
L	24	,, , ,, , ordinary wide neck for solids, unstoppered	500 ml.[1]
L	6	,, , ,, , ordinary wide neck for solids, unstoppered	1000 ml.[2]
	12	,, , specific gravity	25 ml.
	12	,, , ,, ,,	50 ml.
	24	,, , specimen, extra wide mouth, ground-in stoppers	250 ml.
	6	,, , ,, , extra wide mouth, ground-in stoppers	500 ml.
	3	,, , ,, , extra wide mouth, ground-in stoppers	1000 ml.
	12	,, , ,, , wide mouth, plastic screw-tops	250 ml.
	12	,, , ,, , wide mouth, plastic screw-tops	500 ml.
	12	,, , weighing, 7·5 cm. × 2·5 cm.	
L		,, , Winchester quart[3] (or other large bottles)	
*	6	,, , Woulfe, 2-necked, 600 ml.	
	3	Brushes, burette	
	12	,, , camel hair, quill handle, small	
	24	,, , test-tube	
	1	Bulbs, electric, carbon filament	
	1	,, , ,, , neon	
	6	,, , ,, , ordinary torch type, 1·2 volts	
	6	,, , ,, , ,, ,, ,, , 2·5 volts	
	6	,, , ,, , ,, ,, ,, , 3·5 volts	
	6	,, , ,, , two-contact, car type, 6 v., 30 w.	
	6	,, , ,, , ,, ,, ,, ,, , 12 v., 30 w.	
		Bunsen burners—see '*Gas burners*'	
	24	Burettes, with clip and glass jet, 50 ml.	
	3	,, , tap, 50 ml.	

---

[1] Or empty 1-lb. jam-jars (= 450 ml.).

[2] Or empty 2-lb. jam-jars (= 900 ml.).

[3] These accumulate as the large, non-returnable bottles of acid, etc., are emptied.

		Burners—see *Gas burners*
	12	Callipers, inside and outside combined, 4″
	2	,, , vernier gauge, steel
	2	,, , ,, ,, , wood and brass
*	12	Calorimeters, copper, thin, 4″ × 3″
*	12	,, , ,, , ,, , 3″ × 1½″
	1	,, , aluminium, thick, 4″ × 2″ (with 2-holed cork)
	1	,, , copper, thick, 4″ × 2″ (with 2-holed cork)
	1	,, , iron, thick, 4″ × 2″ (with 2-holed cork)
	2 lb.	Candles
ML*	1	Capillarity apparatus
*	1	Cells, electric, Bunsen, primary
	12	,, , ,, , Leclanché, primary, 1000 ml.
	12	,, , ,, , lead accumulator, secondary, 20 amp-hrs.
or	12	,, , ,, , NiFe, ,, , 20 amp-hrs.
		Spares for cells:
	3	Porous pots (spare, for Leclanché cells)
	6	Zinc rods (,, , ,, ,, ,,)
*	1	Chain, land measuring 66 ft.
	1	Chamois leather
	1	Charger,[1] electric, for accumulators, output up to 12 volts, 5 amps.
	2	Chatterton compound, sticks
		Clamps—see 'Stands, retort'
	2	Clamps, G-type, 6″
	12	Clips, Mohr spring
	6	,, , screw
*	36	,, , spring, for plane mirrors
*	1	Clock, stop
L	12	Cloths, polishing
	12	Cobalt glass, pieces
ML	12	Collecting boxes glass-topped
	2	,, ,, (vasculum)
	1	Coloured gelatine transparencies, set of 7 (see page 93)

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[1] If A.C. mains supply is available. The voltage must be stated.

L	2	Commutators (electrical reversing switches)
	1	Compasses, magnetic, large, 3″
	12	,, , ,, , small (for plotting)
*	1	,, , mariners'
	1	,, , ,, (card only)
*	1	,, , prismatic
	1	Condensers, coiled glass tube
	4	,, , Liebig, 10″
*	1	,, , optical
	1	Conductivity can, with metal bars (for comparative conductivity)
ML	12	Cones, flame protectors

Corks (stoppers), to fit apparatus listed

		Cork (solid)	*Rubber*		
			Solid	1-*hole*	2-*hole*
Bottles, reagent, narrow neck, unstoppered	100 ml.	36	12	12	
	250 ml.	36	12	12	
	500 ml.	12	6	6	
Bottles, reagent, wide neck, unstoppered	100 ml.	24			
	250 ml.	36			
	500 ml.	24			
	1000 ml.	6			
Flasks, conical	250 ml.	24	12		12
	500 ml.	12	6		6
Flasks, flat-bottomed	150 ml.	24	6	6	6
	250 ml.	24	6	12	12
	500 ml.	36	6	12	12
	1000 ml.	3	3		3
Flasks, graduated	100 ml.	12			
	250 ml.	12			
	500 ml.	6			
	1000 ml.	6			

		Cork (*solid*)	*Rubber*		
			Solid	1-*hole*	2-*hole*
Flasks, round-bottomed	250 ml.	24		6	6
	500 ml.	12		6	6
	1000 ml.	4		4	4
Flasks, squat, wide neck	150 ml.	4			
Flasks, thermos		6		2	2
Test-tubes, ignition	5″ × ⅝″	36	12	36	
	6″ × ¾″	36	12	12	12
Test-tubes, soda glass	5″ × ⅝″	12	12	12	
	6″ × ¾″	12			12
	6″ × 1″	36		12	12
Tubes, combustion	2 cm. diam.	24		24	
Tubes, U-, plain	15 mm. diam.			24	
Tubes, U-, with side tubes	15 mm. diam.	24			

Also, 24 corks of each of small sizes not named above
24 shives (cork) of each of large sizes not named above.

	2	Cork borers, full sets
	2	,, ,, , $\frac{3}{16}$″ to ⅜″, sets.
	1	Cork borer sharpener
*	1	Cork presser
*	12	Cork sheets, compressed, 18″ square
	24	Crucibles, porcelain, with lids, 25 mm. diam.
	24	,, , ,, , ,, ,, , 50 mm. ,,
	1	,, , nickel, with lid, 35 mm. diam.
*	1	Cryophorus (or Hygrometer, Daniell)
		Cube, Leslie's—see 'Leslie's cube'

	2	Cubes, sets of six different metals, 1 cm.
	2	,, , ,, ,, ,, ,, ,, , 2 cm.
ML	1	Cylinder and bucket[1]
	2	Cylinders, glass, graduated, 10 ml.
	2	,, , ,, , ,, , 25 ml.
	6	,, , ,, , ,, , 100 ml.
	12	,, , ,, , ,, , 250 ml.
	2	,, , ,, , ,, , 500 ml.
	2	,, , ,, , ,, , 1000 ml.
	2	,, , ,, , (for Nessler's reaction)
*	1	Davy lamp
	24	Deflagrating spoons, with jar covers
	2	Desiccators, ordinary, 6″
	2	,, , ,, , 8″
	2	,, , ,, , 10″
	2	,, , ground-in stop-cock, 6″
	1	Diffusion apparatus (pot, cork, tube), for hydrogen
	1	,, ,, (,, , ,, , ,,), for carbon dioxide
*	1	Dip circle
ML	1	Disc, Crova's,[2] cardboard
		,, , Newton's—see 'Newton's disc'
	2	Dishes, crystallizing
	6	Dishes, Petri
		Dissecting apparatus:
L	6	Dishes, enamel, 8″
L	2	,, , ,, , 12″
	12	Forceps, blunt
	12	,, , pointed
	4	Microscopes, students', dissecting
	24	Needles, wooden handle, bent
	24	,, , ,, ,, , straight
	12	,, , Lancet
	12	Scalpels

---

[1] To demonstrate Archimedes' principle.

[2] This can be substituted for Newton's disc on a whirling stand.

	12	Scissors, pointed, 4″
	6	Section lifters
	12	Seekers (probes), blunt
	1	Diver, Cartesian
		Drying paper—see 'Paper'
*	3	Drying towers
		Dusters, for glass—see 'Cloths, polishing'
	60	Dusters, string (swabs)
	1	Dynamo, or motor, 6-volt model
	2 lb.	Ebonite, panels, $\frac{3}{16}$″
	1 lb.	,, , rod
		Egg-timer—see 'Sand-glass'
	1	Elder pith, bundle
	6	Electrodes, carbon rods, with brass terminals
	2	,, , carbon plates, 2″ × 4″, with brass terminals
	12	,, , copper plates, 2″ × 3″, with soldered wire
	12	,, , zinc plates, 2″ × 3″, with soldered wire
	1	Electrolysis of water apparatus, Hoffman's, with 1 pair platinum and 1 pair carbon electrodes
*	1	Eudiometer tube, with platinum electrodes
ML	6	'Eureka' cans (overflow jars)
*	12	Felt covers for calorimeters
	1	Files, round
	6	,, , triangular, 4″
	2	Filter flasks, 250 ml.
	2	,, ,, , 500 ml.
	2000	Filter papers, ordinary, 9 cm.
	2000	,, ,, , ,, , 11 cm.
	200	,, ,, , ,, , 15 cm.
	100	,, ,, , ,, , 32 cm.
	100	,, ,, , special known ash, 11 cm.
	2	Filter pumps, glass
	2	,, ,, , metal

	1	Filter, Wratten, colour, set Nos. 29, 46, 58
	1	Flasks, bolt head, round bottom, with 5-holed rubber cork, 2000 ml.
	24	„ , conical, 250 ml.
	24	„ , „ , 500 ml.
	3	„ , distilling, with side tube, 250 ml.
	3	„ , „ , „ „ „ , 500 ml.
	3	„ , „ , Kjeldahl, long neck, 250 ml.
		Flasks, filter—see 'Filter flasks'
	24	Flasks, flat bottom, 150 ml.
	24	„ , „ „ , 250 ml.
	36	„ , „ „ , 500 ml.
	3	„ , „ „ , 1000 ml.
	12	„ , graduated, 100 ml.
	12	„ , „ , 250 ml.
	6	„ , „ , 500 ml.
	6	„ , „ , 1000 ml.
	24	„ , round bottom, hard glass, 250 ml.
	24	„ , „ „ , ordinary, 250 ml.
	12	„ , „ „ , „ , 500 ml.
	4	„ , „ „ , „ , 1000 ml.
	4	„ , squat, wide neck, 150 ml.
	2	„ , thermos
	2	„ , „ , refill
		Flex, twin, electric—see 'Wire'
		Forceps—see '*Dissection apparatus*'
	1	Funnel, hot-water jacket
	12	Funnels, filter, glass, 7·5 cm.
	12	„ , „ , „ , 10 cm.
	2	„ , „ , „ , 15 cm.
	2	„ , „ , „ , 20 cm.
	2	„ , open, cylindrical, with taps, 100 ml.
	2	„ , separating, stoppered, 100 ml.
	2	„ , „ , „ , 250 ml.
	24	„ , thistle, plain, 12″
	2	„ , „ , 2 bulbs
JE	1	Fuse, porcelain, 5 amps., 500 volts
		Fusewire—see 'Wire'

	1	Galvanometer, 1–0–1 milliamps, bench type, 25 ohms.
*	1	„ , mirror type, with lamp [1] and scale
		Galvanometers—see 'All test instrument'
*	1	Gas burette, with levelling tube, in stand
*	2	Gas pipettes, absorption
		Gas burners (if laboratory has gas installation)
	1	Blowpipe [2] (for foot-operated bellows)
	36	Bunsen burners [2]
	6	Fishtail burners [2]
	2	Meker burners [2]
	2	Ring burners [2]
	2	Gas lead-in porcelain tube, with holed cover for crucible
	24	Gas jars,[3] 6″ to 7½″
	12	„ „ , 10″ to 12″
	2	„ „ , 20″
	36	Gas jar covers, glass, ground one side to fit above
	1	Gauge, micrometer screw, graduated in inches
	1	„ , „ „ , „ „ mm.
ML	1	„ , rain
		Gauge, wire—see 'Wire'
	1 sq. ft.	Gauze, copper wire, 30 mesh to 1 in.
	24 „ „	„ , iron wire, asbestos centre, 4″ sq.
	24 „ „	„ , „ „ , „ „ , 6″ sq.
	24 „ „	„ , „ „ , plain, 6″ sq.
*	1	Geissler tubes,[4] set of 5
	250 g.	Glass beads (or small glass balls)
	4	Glass blocks, cubes, 40 mm.
	12	„ „ , rectangular, 10 × 4·5 × 2 cm.
	4	„ „ , semicircular, 6 cm. diam.
	2	Glass, ground, plate, 15 cm. square
*	1	Glass prism, triangular, optically worked, 60°, 60°, 60°, 25 mm.

---

[1] Lamp specification, according to voltage, must be stated.

[2] The type of plant and/or gas used, coal-gas, petrol-gas, etc., must be stated.

[3] Jam-jars can be used as substitutes.

[4] An induction coil is needed to demonstrate Geissler tubes.

*	1	Glass prism, triangular, ordinary, hollow, 60°, 60°, 60°
	6	„ „ , „ , „ , solid, 60°, 60°, 60°, 50 mm.
	2	„ „ , „ , „ , solid, 90°, 60°, 30°, 50 mm.
	2	„ „ , „ , „ , solid, 75°, 75°, 30°, 50 mm.
	6	„ „ , „ , „ , solid, 90°, 45°, 45°, 50 mm.
	500 g.	Glass rod, 4 mm.
	1500 g.	„ „ , 6 mm.
	1500 g.	„ „ , 8 mm.
	1000 g.	Glass tubing, capillary bore, 1 mm. to 2 mm.
	5000 g.	„ „ , soda glass, outside diam. 5 mm. to 8 mm.
	5000 g.	„ „ , „ „ , „ „ 10 mm. to 20 mm.
	2000 g.	„ „ , „ „ , „ „ 40 mm.
	6	„ „ , thick, hard, 4½″ long × 2½″ diam.
	500 g.	Glass wool
	6	Glasses, clock, 10 cm. diam.
	48	„ , watch, up to 6·5 cm. diam.
	1	Grease, tube of, for rubber
*	3	Hare's apparatus, 3-limbed tubes
	3	Holders, electric, small b.c.,[1] batten (car lamp size)
	3	„ , „ , „ „ , pendant (car lamp size)
*	1	Hope's apparatus
	2	Hydrometers, 0·800–1·000
	2	„ , 1·000–1·200
	1	„ , 1·200–1·400
	1	„ , 0·700–1·000
	1	„ , 1·000–2·000
	1	„ , for lead accumulator acid, with syringe
	2	„ , Nicholson's, brass

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[1] Fitting for '*bayonet cap*' type of lamp.

*	1	Hygrometer, Daniell's
*	1	,, , Regnault's
	1	,, , wet and dry bulb
*	2	Hypsometer, glass
ML	1	Inclined plane, with brass roller
*	1	Induction coil, 6-volt
	2	Ink, Indian, black, bottles
		Iron bottles—see 'Bottles'
	2	Key, plug type
	2	,, , tapping
*	2	Kipp's apparatus
	1	Klinostat [1]
	100	Labels, herbarium, not gummed
	200	,, , microscope slide, not gummed
	200	,, , plain, 2″ × ½″, not gummed
	500	,, , ,, , 3″ × ¾″, not gummed
		Lamps, electric—see 'Bulbs'
	3	Lenses, double convex, 25 mm. diam., 5 cm. focal length
	3	,, , ,, ,, , 25 mm. diam., 10 cm. focal length
	3	,, , ,, ,, , 25 mm. diam., 15 cm. focal length
	4	,, , ,, ,, , 50 mm. diam., 20 cm. focal length
	4	,, , ,, ,, , 50 mm. diam., 30 cm. focal length
	4	,, , ,, ,, , 50 mm. diam., 50 cm. focal length
	4	,, , ,, ,, , 50 mm. diam., 100 cm. focal length
	1	,, , double concave, 25 mm. diam., 5 cm. focal length
	1	,, , ,, ,, , 25 mm. diam., 10 cm. focal length
	1	,, , ,, ,, , 25 mm. diam., 15 cm. focal length

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[1] Electrical klinostat if mains supply available: the voltage must be stated.

	2	Lenses, double concave, 50 mm. diam., 20 cm. focal length
	2	,, , ,, ,, , 50 mm. diam., 30 cm. focal length
	2	,, , ,, ,, , 50 mm. diam., 50 cm. focal length
	2	,, , ,, ,, , 50 mm. diam., 100 cm. focal length
	2	,, , cylindrical, concave, 50 mm. × 50 mm.
	2	,, , ,, , convex, 50 mm. × 50 mm.
	1	,, , plano-convex, 50 mm. diam.
	1	,, , plano-concave, 50 mm. diam.
	12	,, , hand magnifying
	3	,, , watchmakers', 4″ focal length
		Lenses, half—see 'Ray apparatus'
ML*	1	Leslie's cube
	1	Liquid level apparatus
	100	Litmus papers (books), blue
	50	,, ,, (,,), red
	10 g.	Lycopodium powder
*	1	Magdeburg hemispheres, pair
	6	Magnets, cylindrical, 50 × 10 cm.
	1	,, , electro-, horse-shoe model
*	1	,, , ,, , more efficient type
	3	,, , horse-shoe, parallel limbs
	6	,, , rectangular, 50 × 10 × 10 mm.
	6	,, , ,, , 100 × 10 × 10 mm.
	2	,, , rectangular, in box with keepers
*	2	,, , Robinson ball-ended
*	1	Magnetometer, deflecting
	1	Measure, enamel, graduated in fluid ounces and litres
*	1	Measuring tape, steel, 66 feet
ML	1	Mercury tray, wooden, 24″ × 18″
	1 sq. ft.	Metal sheet, aluminium, $\frac{1}{32}$″ thick
	1 ,, ,,	,, ,, , brass, $\frac{1}{32}$″ thick
*	1	Model, anatomical, eye
*	1	,, , ,, , ear

*	1	Model, anatomical, larynx
	2	Microscopes, students'
	1	,, , 3-nose-piece, Abbé condenser, iris; fine focusing; one oil-immersion objective
	200	Microscope slides
	12	,, ,, , with cavity
	½ oz.	Microscope slide cover slips
	3	Mirrors, concave, 25 mm. diam., 5 cm. focal length
	3	,, , ,, , 25 mm. ,, , 10 cm. ,, ,,
	6	,, , ,, , 50 mm. ,, , 15 cm. ,, ,,
	6	,, , ,, , 50 mm. ,, , 20 cm. ,, ,,
	6	,, , ,, , 50 mm. ,, , 30 cm. ,, ,,
*	1	,, , ,, , 30 cm. ,, , 15 cm. ,, ,, , on stand
	3	,, , convex, 25 mm. ,, , 5 cm. focal length
	3	,, , ,, , 25 mm. ,, , 10 cm. ,, ,,
	6	,, , ,, , 50 mm. ,, , 15 cm. ,, ,,
	6	,, , ,, , 50 mm. ,, , 20 cm. ,, ,,
	6	,, , ,, , 50 mm. ,, , 30 cm. ,, ,,
*	1	,, , ,, , 30 cm. ,, , 15 cm. ,, ,, , on stand
	1	Mirrors, cylindrical, concave, metal
	1	,, , ,, , convex, ,,
	36	,, , plane, 7·5 cm. × 2·5 cm.
ML	1	Monochord—and see under 'Wire'
	2	Mortars, with pestles, 10 cm.
	2	,, , ,, ,, , 15 cm.
		Motor, electric—see 'Dynamo'
	1	Mu metal rod
	4	Needles, knitting, steel
ML	1	Newton's disc, on whirling stand, 20 cm. diam.
	1	Oil stone, fine
*	6	Opisometers
		Optical apparatus—see 'Ray apparatus'
*	1	Organ pipe, open, wood, with loose-fitting end stop
*	1	,, ,, , ,, , metal, reed

	1	Oven, air
	1	,, , steam, constant level, combined with still [1]
	2	Pans, balance [2]
	100	Paper, drying,[3] for botanical specimens, sheets
	2	,, , emery, sheets
	6	,, , sand, assorted grades, sheets
	100	,, , squared, 27 × 21 cm., ruled cm., sheets
	8 oz.	Paste, herbarium
	3	Pencils, grease, assorted colours
	1	Pendulum bob, lead, with screw eye, ½″ diam.
	1	,, ,, , ,, , ,, ,, ,, , ¾″ ,,
	6	,, ,, , ,, , ,, ,, ,, , ⅞″ ,,
	6	,, ,, , ,, , ,, ,, ,, , 1″ ,,
	1	,, ,, , ,, , ,, ,, ,, , 1½″ ,,
	1	,, ,, , ,, , ,, ,, ,, , 2″ ,,
	1 gross	Pins, blanket
	½ lb.	,, , brass, plated, 2″
	3	,, , entomological, assorted boxes
	6	Pipettes, 10 ml.
	24	,, , 20 ml. or 25 ml.
	2	,, , 50 ml.
	2	,, , 100 ml.
	2	,, , curved, for use with barometer tubes
	2	,, , graduated, 1 ml.
	2	,, , ,, , 5 ml.
	2	,, , ,, , 10 ml.
	1	Plum bob, brass
		Poles—see 'Electrodes'
	6	Porcelain plates (tiles), white, 4″ square
	12	,, ,, (,,), black and white, 4″ square
*	12	,, ,, , spotting, with 6 cavities each
	6	Porous pots for diffusion and osmosis experiments
ML*	1	Potentiometer, single wire, 1 metre
*	1	Potometer, Farmer's
*	1	Press, hydraulic, model

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[1] Electric still if mains supply available: the voltage must be stated.

[2] Can be made from lids of tins.

[3] Newspaper can be used.

TUTE OF EDUCATION FOR WO
Dept. of Extension
SERVICE

	2	Pulleys, aluminium, mounted on clamp for bench end
	2	,, , ,, , mounted on rod for retort stand
	12	,, , ,, , ordinary, single
	12	,, , ,, , ,, , double
	6	,, , ,, , ,, , triple
*	1	,, , Weston differential, 5 cwt.
	1	Pump, Guericke, with plate
	1	,, , bicycle
	3	Ray boxes, with 12-volt lamps
	1	Ray demonstration apparatus, with plane and cylindrical mirrors, semi-circular trough, half lenses, etc.
	2	Razors, hollow ground, with strop
	2	Resistances, electric, fixed, 1·0 ohm
	2	,, , ,, , ,, , 5·0 ohms
	2	,, , ,, , ,, , 10·0 ohms
	2	,, , ,, , ,, , 20·0 ohms
	2	,, , ,, , ,, , 100·0 ohms
	2	,, , ,, , variable (rheostats), 0–10 ohms
	1	,, , ,, , variable (rheostats), 0–100 ohms
JE		,, , ,, , variable, assorted
	12	Retorts, glass, 500 ml.
*	1	Revolution counter
	1	Ring, soft iron, 2″ diam.
	36	Rulers, ordinary, 12″ (30 cm.)
	12	,, , half-metre scales
	24	,, , metre scales
	2	,, , ,, ,, , reading both ways
	36	Saddles, brass, assorted
	1	Sand glass, 5 minutes
	1 yd.	Sausage skin paper
		Scales—see 'Balances'
		Scalpels—see '*Dissection apparatus*'
	2	Scissors, ordinary, 6″

	1	Sextant, model
	1	Sieve, 10 mesh
	1	,, , 20 ,,
	1	,, , 30 ,,
	1	,, , 40 ,,
	1	Siren, perforated disc [1]
		Skeletons [2]
	36	Slides, lantern, cover glasses
*	1	Slide rule, 10″
	1 lb.	Solder, soft
	1	Soldering iron
		Sonometer—see 'Monochord'
	24	Spatulas, bone, 10 cm.
	2	,, , nickel
*	12	Spheres, rustless steel, $\frac{3}{8}''$
*	2	Spherometers
	6	Spirit lamps, brass
	1	Spirit level, ordinary
	1	,, ,, , circular, 1″ diam.
		Spoons—see 'Deflagrating spoons'
	12	Springs, extension, 6″ × $\frac{1}{4}''$
	6	,, , ,, , 8″ × $\frac{1}{4}''$
	1	Staining trough, for 20 slides
	24	Stands, retort, rustless, 18″
	6	,, , ,, , ,, , 24″
	6	,, , ,, , ,, , 36″

Retort stand accessories

18	Clamps, ordinary
18	,, , large
24	Double bosses
6	Rings, 2″
6	,, , 3″
6	,, , 4″
2	,, , 6″

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[1] This can be substituted for Newton's disc on a whirling stand.

[2] These should be obtained and set up locally.

	18	Stands, wooden, burette, single
	12	,, , ,, , filter, 2-ring
ML	2	,, , ,, , pipette (to take all pipettes)
ML	18	,, , ,, , test-tube (12 holes)
*	2	Steam cans
*	1	Steam engine, model
*	1	Steelyard, ordinary
	1	,, , Danish
*	1	Stereoscope, with suitable pictures for viewing
	1 set	Stencils, interlocking, 1″
	1 ,,	,, , 'Uno' type UC 2, with pen
	1 ,,	,, , ,, ,, UC 3, ,, ,,
	1 ,,	,, , ,, ,, UC 4, ,, ,,
		Still—see 'Oven, steam'
	1	Stone, carborundum, oval section, fine
		Stone, oil—see 'Oil stone'
ML	6	Stools, balance
	2	Stopcocks, glass, 2 mm. bore
	3	Switches, electric, 2-way, 12-volt
	1	Syringe, glass, 50 ml.
	1	Syringe, hypodermic
	6	T-pieces, glass (size of bore as required)
	2	,, , brass (,, ,, ,, ,, ,,)
L	1	Tap (faucet, bent-down nozzle), for demonstration
L	2	Tape, insulating, rolls
L	1	Telephone receiver and mouthpiece
*	1	Telescope, astronomical
	24	Terminals, electric, brass, 4BA nuts and washers
	24	,, , ,, , ,, , fitted wood screws
	12	,, , ,, , spade, black
	12	,, , ,, , ,, , red
	6	,, , ,, , crocodile pattern, large
	6	,, , ,, , ,, ,, , small
	1 gross	Test-tubes, ignition, 3″ × $\frac{1}{2}$″
	1 ,,	,, ,, , ,, , 5″ × $\frac{5}{8}$″
	3 doz.	,, ,, , ,, , 6″ × 1″
	6 gross	,, ,, , ordinary soda, or resistance, glass, 5″ × $\frac{5}{8}$″

	½ gross	Test-tubes, ordinary soda, or resistance, glass, 6″ × ¾″
	36	,, ,, , ordinary soda, or resistance, glass, 6″ × 1″
	24	Test-tube holders
*	1	Thermopile
	1	Thermometers, alcohol, wall, C and F scales
*	1	,, , bimetallic
	1	,, , clinical
	1	,, , maximum and minimum (Six's)
	18	,, , mercury, − 10° to + 110° C.
	2	,, , ,, , 20° to 220° F.
	6	,, , ,, , − 10° to + 210° C.
	2	,, , ,, , − 10° to + 310° C.
	12	,, , ,, , not graduated
*	1	Thermoscope, differential
	12	Tongs, crucible, brass
	18	Triangles, pipeclay over wire
	30	Tripods, triangular, iron (size according to type of heating device used)
	6	,, , round, iron (size according to type of heating device used)
	3	Troughs, glass, circular, 25 cm. diam.
	2	,, , ,, , rectangular, 20 × 16 × 16 cm.
*	12	,, , stoneware,[1] circular, 25 cm. diam.
	2	Tubes, barometer, siphon
	3	,, , ,, , straight, 36″
	12	,, , calcium chloride, plain, straight, one bulb
	12	,, , combustion, hard glass, 25 cm. × 2 cm.
	6	,, , ,, , ,, ,, , 50 cm. × 2 cm.
		Tubes, glass, ordinary—see 'Glass tubing'
	3	Tubes, J-type, Boyle's law
*	1	,, , graduated, glass, with tap, 50 cm.
	½ gross	,, , specimen, flat-bottomed, with corks, 2″
	½ ,,	,, , ,, , ,, ,, , ,, ,, , 3″
	½ ,,	,, , ,, , ,, ,, , ,, ,, , 4″
	3 doz.	,, , ,, , ,, ,, , ,, ,, , 6″

[1] Not wanted if the laboratory benches are provided with sinks.

	6	Tubes, U-type, plain, 15 mm. diam.
	12	,, , ,, , with side tubes, 15 mm. diam.
	3	,, , ,, , 60 cm. limbs (for balancing liquid columns)
	24 ft.	Tubing, rubber, black, $\frac{3}{16}$″
	6 ft.	,, , ,, , ,, , $\frac{1}{4}$″
	120 ft.	,, , ,, , red, $\frac{3}{8}$″ (for gas burners, if used)
	10 ft.	,, , ,, , pressure, narrow bore, $\frac{1}{8}$″
	10 ft.	,, , ,, , ,, , ,, ,, , $\frac{3}{16}$″
	2	Tuning forks, c (256)
	1	,, ,, , d
	1	,, ,, , e
	1	,, ,, , f
	1	,, ,, , g
	1	,, ,, , a′
	1	,, ,, , b′
	2	,, ,, , c′ (512)
ML	1	Vernier model, large demonstration, 2 m. long (by tenths)
	6	,, ,, , 1 ft. long, inches and cm. (by tenths)
		Voltameter, for electrolysis of water—see 'Electrolysis apparatus'
	3	Voltmeters, bench type, moving coil, 0–3 volts
	1	,, , ,, ,, , ,, ,, , 0–20 volts
	1	,, , ,, ,, , moving iron, 0–10 volts
*	1	,, , 0–250 volts A.C.[1]
	1	Wall chart, human physiology, set
*	1	Watch, stop
	1 lb.	Wax, black
	1 lb.	,, , sealing
	2	Weight thermometers
	3	Weights, fractional, 10 mg.
	3	,, , ,, , 20 mg.
	3	,, , ,, , 50 mg.
	3	,, , ,, , 100 mg.
	3	,, , ,, , 200 mg.

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[1] If mains supply of electricity is available.

3	Weights, fractional, 500 mg.
1 set	,, , iron, hexagonal, with ring, 100 g. to 10 Kg.
1 ,,	,, , ,, , slotted, with carrier, 500 g. to 5 Kg.
20	,, , brass, slotted, 5 g.
20	,, , ,, , ,, , 10 g.
40	,, , ,, , ,, , 20 g.
20	,, , ,, , ,, , 50 g.
10	Weight-hanging carriers for above, 50 g.
1 set	Weights, brass, 4 oz. to 2 lb.
1	Wheatstone bridge, 1 metre
1	Wheel and axle
6	Wheels, contrate assorted (e.g. extra to No. 6, or higher, 'Meccano' set)
6	,, , gear, assorted (e.g. extra to No. 6, or higher, 'Meccano' set)
6	,, , pinion, assorted (e.g. extra to No. 6, or higher, 'Meccano' set)
2 oz.	Wire, brass, bare, S.W.G.[1] 18
2 oz.	,, , ,, , ,, , ,, 22
2 oz.	,, , ,, , ,, , ,, 26
1	,, , ,, , spiral (to demonstrate wave motion)
½ lb.	,, , copper, bare, S.W.G. 16
½ lb.	,, , ,, , ,, , ,, 18
1 lb.	,, , ,, , D.C.C.,[2] S.W.G. 18
1 lb.	,, , ,, , ,, , ,, 22
½ lb.	,, , ,, , ,, , ,, 26
½ lb.	,, , ,, , ,, , ,, 32
1 lb.	,, , 'eureka' or 'contra', D.S.C.,[3] S.W.G. 22
½ lb.	,, , ,, ,, ,, , ,, , ,, 32
1	,, , fuse, 5 amp., reel
1	,, ,, , 2 amp., reel
2	,, , iron, reels
¼ lb.	,, , nickel-chrome, S.W.G. 24
¼ lb.	,, , ,, ,, , ,, 36
½ lb.	,, , steel, bare, S.W.G. 22
2 oz.	,, , ,, , ,, , for monochord

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[1] Standard Wire Gauge.

[2] Double Cotton Covered.

[3] Double Silk Covered.

50 yds.	Wire, twin flex, bell
50 yds.	,, , twin flex,[1] red and black, to take 3 amps., 220 volts
1	Wire gauge, S.W.G. 1–40

TOOLS

A Science teacher needs some tools. If the school has a handwork class which includes carpentry in its activities, he will be wise to persuade the handwork teacher to arrange for the carpentry jobs to be done. If this is possible, the provision of the usual woodworking tools need not concern him. But for the other various tasks that may fall to his lot the following, *not* included in the LIST OF APPARATUS above, are likely to be needed by a progressive teacher.

1	Chisel, cold, 8″
1	Drill, hand
1	Drill countersink bit
1 set	Drills, twist, $\frac{1}{32}$″ to $\frac{1}{4}$″
1	File, flat, 12″
1	,, , half-round, 8″
1	,, , round (rat-tail), $\frac{1}{4}$″ diam.
1	,, , ,, (,,), $\frac{1}{16}$″ diam.
1	Glass cutter (steel wheels)
1	Hack saw
12	,, ,, blades
1	Hammer, claw, large
1	,, , cross pein, 1 lb.
1	Oil can
1	Pliers, ordinary, wire cutting, flat nose
1	,, , ,, , long, round nose
1	Screw driver, large
1	,, ,, , medium
1	,, ,, , small
1	,, ,, , watchmaker's
1	Snips, tinman's, 8″
1	Spanner, adjustable, 6″
1	Vice, 3″, for attaching to bench with clamp

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[1] If mains supply of electricity available.

PART II—LIST OF CHEMICALS

Note—Attention is drawn to the comments on particular chemicals given in Chapter XI, pages 262–5.

Attention is also drawn to the symbols X, P, D, A, against various items in the following list:

X—*Dangerous chemicals*—Substances marked 'X' are subject to special conditions and rates when transported by sea or rail, owing to their dangerous nature. Care should be taken to anticipate the number and quantity of such chemicals likely to be required. Most of them can then be ordered at the same time, thus reducing the number of separate consignments, with a corresponding decrease in transport charges.

P—*Poisons*—Substances marked 'P' are poisonous and must be kept under lock and key. The science teacher is directly responsible for their security and safe use. (The three common acids, hydrochloric, nitric and sulphuric, are exceptions in that, being in frequent use, they need not be locked up. But the teacher must still ensure that they are never misused.)

D—*Hygroscopic and deliquescent substances*—Chemicals marked 'D' rapidly deteriorate, especially in the tropics, when exposed to air, owing to absorption of water. They should be ordered in small containers, to be opened only one at a time as required. It is advisable to put a small quantity into a separate labelled bottle and to re-seal the original container immediately. (Such substances will usually keep indefinitely provided that the original container remains unopened.)

A—*Purest quality*—Substances marked 'A' should be ordered in the quality recommended by the manufacturers for analytical work, so that they may be used for this purpose when required.

WQ—Winchester quart—Many firms supply chemical liquids in this unit. It is an old measure, approximately equal to 5 pints or 2½ litres.

X	500 g.	Acetone
	500 g.	Acid, acetic, glacial
	250 g.	,, , boric, powder
D	500 g.	,, , carbolic (phenol)
	250 g.	,, , citric

X	8 WQ	Acid, hydrochloric, pure
X	3 WQ	,, , nitric, pure
	250 g.	,, , oleic, technical
P A	250 g.	,, , oxalic
	100 g.	,, , palmitic, technical
		Acid, picric—see '*Fixatives*'
	50 g.	Acid, pyrogallic (pyrogallol)
	250 g.	,, , stearic, technical
D X	5 WQ	,, , sulphuric, pure
	100 g.	,, , tartaric
	25 g.	,, , uric
X	500 g.	Alcohol, ethyl, absolute
X	8 WQ	,, , ,, (methylated spirit)
X	2 WQ	,, , ,, (rectified spirit)
X	250 g.	Alcohol, methyl (wood naphtha)
	250 g.	Alum, chrome
	250 g.	,, , ferric
	1 Kg.	,, , potassium
	100 g.	Aluminium, metal, foil
	100 g.	,, , ,, , powder
	250 g.	,, , ,, , sheet, 24-gauge
	100 g.	,, , ,, , wire
	100 g.	Aluminium oxide
X	4 WQ	Ammonia solution (ammonium hydroxide) S.G.: 0·910
	250 g.	Ammonium bicarbonate
	500 g.	,, carbonate
	3 Kg.	,, chloride, commercial
	1 Kg.	,, ,, , pure
A	250 g.	,, molybdate
	250 g.	,, sodium phosphate (microcosmic salt)
	500 g.	,, sulphate, pure
D	50 g.	,, thiocyanate
X	100 g.	Amyl acetate
	500 g.	Aniline
	25 g.	,, hydrochloride solution
	2 Kg.	Anthracite
P	100 g.	Antimony, metal, powder

P	100 g.	Antimony potassium tartrate (tartar emetic)
P	50 g.	,, sulphide, red
P	250 g.	Arsenic trioxide
	100 g.	Asbestos lump
	100 g.	,, paper
	5 g.	,, platinized, 5%
	100 g.	,, tape
	250 g.	,, wool
P D A	500 g.	Barium chloride
P A	500 g.	,, hydroxide
P D A	250 g.	,, nitrate
P	50 g.	,, peroxide
X	1 WQ	Benzene
	25 g.	Bile salts (or local ox gall-bladder)
		Bleaching powder—see 'Calcium hypochlorite'
	500 g.	Borax
	25 g.	Cadmium chloride
X	100 g.	Calcium, metal, turnings
X D	500 g.	Calcium carbide
	500 g.	,, carbonate (chalk soil sample)
	3 Kg.	,, ,, (marble chips)
	1 Kg.	,, ,, , pure
D	3 Kg.	,, chloride, commercial, dry granulated
	100 g.	,, ,, , hydrated, pure
D	1 Kg.	,, hypochlorite (bleaching powder)
	250 g.	,, nitrate, hydrated, pure
D	500 g.	,, oxide, pure
D	3 Kg.	,, ,, (quicklime), commercial, in 500 g. lots
	250 g.	,, phosphate, $CaHPO_4$, pure
	2 Kg.	,, sulphate (plaster of Paris)
	100 g.	,, ,, , pure
	25 g.	,, sulphide (luminous)
	50 g.	Camphor, block, synthetic
	100 g.	Canada balsam, solid
	100 g.	,, ,, , in Xylol
		Carbon, blocks—see 'Charcoal'
	100 g.	Carbon (graphite), lumps

	250 g.	Carbon (graphite), powder
	500 g.	,, (lamp black)
X	1 Kg.	Carbon disulphide
	500 g.	,, tetrachloride
	100 g.	Carborundum paste, coarse
	100 g.	,, ,, , fine
	100 g.	Casein
		Chalk—see 'Calcium carbonate'
	1 Kg.	Chalk, French
	500 g.	Charcoal, animal
	24	,, , blocks, 3″ × 1″
	500 g.	,, , pure (activated)
	500 g.	,, , wood [1]
	100 g.	Chatterton compound
		China clay—see 'Kaolin'
P	500 g.	Chloroform
	25 g.	Chlorophyll
	25 g.	Chromium, metal
		Chrome alum—see 'Alum'
	2 Kg.	Coal, bituminous
		—see also 'Anthracite', 'Lignite'
	25 g.	Cobalt, metal, lumps
D	100 g.	Cobalt chloride
	250 g.	Copper, metal, filings
	500 g.	,, , ,, , foil
	1 Kg.	,, , ,, , turnings
	500 g.	Copper carbonate
	500 g.	,, oxide (cupric), black, pure
	100 g.	,, ,, (cuprous)
	3 Kg.	,, sulphate, pure
	500 g.	Cotton wool
X	100 g.	Cresol
	100 g.	Dead black
	250 g.	Dextrin, technical
		Dextrose—see 'Glucose'
	25 g.	Diastase
	25	Dutch metal, sheets

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[1] To be obtained locally.

X	1 WQ	Ether, S.G.: 0·720
X	1 WQ	„ , petroleum, B.P.: 40°–60° C.
X	100 g.	Ethyl acetate
		Ethyl alcohol—see 'Alcohol'
	25 g.	Fellis Bovini extract
	25 g.	Filler (for graduation marks on glass)
		Fixatives:
	50 ml.	Bouin's fluid
	50 ml.	Chromic acid
P X	50 ml.	Picric acid
	25 g.	Fluorescin (uranin)
	2 WQ	Formaldehyde (formalin) 40%
		French chalk—see 'Chalk'
	25 g.	Fructose (laevulose)
	100 g.	Gelatin, sheet or powder
	250 g.	Glass wool
	1 Kg.	Glucose (grape sugar, dextrose)
	1 WQ	Glycerin (glycerol), pure, S.G.: 1·260
	1 Kg.	Glycerin jelly (glycerin and gelatin)
	100 g.	Gold size
		Graduation filler—see 'Filler'
		Graphite—see 'Carbon'
	500 g.	Gum arabic
		„ shellac (French polish can be used)
	1 Kg.	Hydrogen peroxide, 10-volume
		Indicators:
	25 g.	Bromophenol blue
	100 g.	Litmus
	25 g.	Methyl orange
	25 g.	Phenolphthalein
	25 ml.	Phenol red
	250 ml.	'Universal' indicator —see also 'Litmus papers' (Part A)
	100 g.	Iodine, resublimed

25 g.	Iodoform
1 Kg.	Iron, metal, filings, fine
100 g.	,, , ,, , powder, reduced
50 g.	,, , ,, , wire (reels)
	Iron (ferric) ammonium sulphate—see 'Alum, ferric'
500 g.	Iron (ferrous) ammonium sulphate
D 250 g.	,, (ferric) chloride, pure
D 250 g.	,, (ferrous) chloride
250 g.	,, oxide, brown
250 g.	,, ,, , magnetic, lumps
250 g.	,, ,, , red
100 g.	,, (ferric) phosphate
100 g.	,, (,,) sulphate
500 g.	,, (ferrous) sulphate
2 Kg.	,, sulphide, plates
100 g.	Kaolin
1 WQ	Kerosene [1]
100 g.	Lactose
	Lamp black—see 'Carbon'
1 Kg.	Lead, metal, foil
1 Kg.	,, , ,, , shot, large
1 Kg.	,, , ,, , ,, , small
250 g.	,, , ,, , wire, S.W.G. 11
P A 500 g.	Lead acetate
500 g.	,, carbonate, precipitated
500 g.	,, nitrate, pure
500 g.	,, oxide, litharge
500 g.	,, ,, , red
500 g.	,, ,, (peroxide), brown
2 Kg.	Lignite—see also 'Coal'
50 gr.	Lithium chloride
	Litmus—see '*Indicators*'
100 g.	Magnesium, metal, powder
100 g.	,, , ,, , ribbon, (rolls)
25 g.	,, , ,, , wire

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[1] Usually obtainable locally. The quantity to be stocked will depend upon the number and the extent of its uses in the laboratory.

	500 g.	Magnesium carbonate, light
D	100 g.	,, chloride, pure
	250 g.	,, nitrate
	250 g.	,, oxide, heavy
	1 Kg.	,, sulphate, pure
	1 Kg.	Manganese dioxide, pure, powdered
		Marble—see 'Calcium carbonate'
P	2 Kg.	Mercury, metal
P	100 g.	Mercury (mercuric) chloride (corrosive sublimate)
P	100 g.	,, (mercurous) chloride (calomel)
P	250 g.	,, (mercuric) oxide
P	100 g.	,, (mercurous) oxide
P	50 g.	,, (mercuric) sulphate
P	25 g.	,, (mercuric) sulphide (vermilion)
		Microcosmic salt—see 'Ammonium sodium phosphate'
	100 ml.	Millon's reagent
X	250 ml.	Naphtha, mineral
		Naphtha, wood—see 'Alcohol, methyl'
	2 Kg.	Naphthalene, flakes
	1 Kg.	,, , marbles
	25 g.	Naphthol, alpha-
		Nessler's reagent [1]
	100 g.	Nickel, metal, foil
	250 g.	Nickel sulphate
		Nitre—see Potassium nitrate
		Oils:
	25 g.	Cedarwood
	100 g.	Clove
	1 WQ	Linseed, boiled
	1 Kg.	Oxygen mixture
	25 g.	Pancreas, dried
	1 WQ	Paraffin, medicinal
	3 Kg.	Paraffin wax, M.P.: 122°–125° F.
	3 Kg.	,, ,, , M.P.: 135°–140° F.

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[1] To be made up as required.

2 Kg.	Peat
25 g.	Pepsin
100 g.	Permutit
	Petroleum ether—see 'Ether'
	Phenol—see 'Acid, carbolic'
	Phenolphthalein—see '*Indicators*'
250 g.	Phosphorus, red
500 g.	,, , yellow, sticks
	Plaster of Paris—see 'Calcium sulphate'
25 g.	Potassium, metal (in naphtha, mineral)
100 g.	Potassium bicarbonate, pure
100 g.	,, bisulphate
250 g.	,, bromide
D 500 g.	,, carbonate, dry
2 Kg.	,, chlorate
A 250 g.	,, chloride
250 g.	,, chromate
P 250 g.	,, cyanide, commercial
500 g.	,, dichromate, pure
A 100 g.	,, ferricyanide
A 100 g.	,, ferrocyanide
D 500 g.	,, hydroxide, pellets
D 500 g.	,, ,, , sticks
100 g.	,, iodide
A 2 Kg.	,, nitrate (nitre)
A 1 Kg.	,, permanganate
100 g.	,, phosphate, dihydrogen
500 g.	,, stearate, green (soft soap)
500 g.	,, sulphate, pure
D A 100 g.	,, thiocyanate
	Pyrogallol—see 'Acid, pyrogallic'
100 ml.	Rennin (rennett)
100 g.	Resin (rosin)
	Rochelle salt—see 'Sodium potassium tartrate'
	Rock salt—see 'Sodium chloride'
	Sal ammoniac—see 'Ammonium chloride'
	Saltpetre—see 'Potassium nitrate'
25 g.	Saponin

		Shellac—see 'Gum'
	500 g.	Silica gel, coarse
	100 g.	Silicon
A	100 g.	Silver nitrate
	500 g.	Soap, Castile
		,, , common [1]
		Soap, soft—see 'Potassium stearate'
D	500 g.	Soda lime, granular, medium
		Soda, washing—see 'Sodium carbonate'
X	100 g.	Sodium, metal (in naphtha, mineral)
	250 g.	Sodium acetate
	2 Kg.	,, bicarbonate
	100 g.	,, bisulphate
	250 g.	,, bisulphite
		Sodium borate—see 'Borax'
D	100 g.	Sodium bromide
	1 Kg.	,, carbonate, anhydrous
	3 Kg.	,, ,, , crystalline
	3 Kg.	,, chloride, pure
D	1 Kg.	,, ,, , (rock salt)
	250 g.	,, citrate
D	1 Kg.	,, hydroxide, flakes
D	1 Kg.	,, ,, , pellets
D	1 Kg.	,, ,, , sticks
	500 ml.	,, hypochlorite, solution
D	500 g.	,, nitrate, pure
	250 g.	,, phosphate, dihydrogen
A	250 g.	,, ,, , disodium
	250 g.	,, ,, , trisodium
	250 g.	,, potassium tartrate (Rochelle salt)
	500 g.	,, silicate (waterglass)
	500 g.	,, sulphate, anhydrous
	2 Kg.	,, ,, , crystalline
	1 Kg.	,, sulphite, anhydrous
	1 Kg.	,, thiosulphate
	100 ml.	Soldering fluid (1 tin)

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[1] As obtainable locally.

		Stains:
	25 g.	Aniline sulphate
	25 g.	Carmine
	25 g.	Eosin yellow
	25 ml.	Haematoxylin, Delafield's
	25 ml.	Leishmann's
	25 ml.	Light green
	25 ml.	Methylene blue
	25 g.	Safranin
	25 ml.	Sudan III
	500 g.	Starch, potato
	500 g.	,, , wheat
	500 g.	Steel filings
D	50 g.	Strontium chloride
		Sugar, cane, ordinary [1] (sucrose)
		Sugar, fruit—see 'Fructose'
		Sugar, grape—see 'Glucose'
		Sugar, milk—see 'Lactose'
	1 Kg.	Sulphur, flowers
	50 g.	,, , rhombic
	1 Kg.	,, , roll
		Test papers—see 'Litmus papers' (Part A)
	25 g.	Thymol
	250 g.	Tin, metal, granulated
D	100 g.	Tin (stannous) chloride
X	500 g.	Toluene
	500 g.	Turpentine
	50 g.	Urea, technical
	25 g.	Urethane
	1 Kg.	*Vaseline* (petroleum jelly)
X	1 WQ	Xylene, pure
	250 g.	Zinc, metal, foil
	3 Kg.	,, , ,, , granulated, commercial
	250 g.	Zinc carbonate
D	250 g.	,, chloride, sticks
	500 g.	,, oxide
	500 g.	,, sulphate, pure

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[1] Usually obtainable locally.

APPENDIX F

Books for the General Science Library

There are hundreds of books on every aspect of science, and the teacher has to make his own appropriate selection. The following list is intended as a *guide* to the choice of books suitable for a course in General Science.

(F)—published in France (French language)
(G)—published in Great Britain
(U)—published in the United States of America

1. HISTORICAL [1]

The '*Living Names*' Series (certain volumes). Oxford University Press (G)
ANTHONY. *Science and its Background.* Macmillan (G)
BUTTERWORTH. *Origins of Modern Science.* Bell (G)
CALDER. *Profile of Science.* Allen & Unwin (G)
CROWTHER. *Famous American Men of Science.* Norton (U)
DE KRUIF. *Men against Death.* Harcourt, Brace (U)
DEVAUX. *Histoire de l'électricité.* Presses Universitaires de France (F)
FARRINGDON. *Greek Science.* Penguin (G)
HARVEY-GIBSON. *Two Thousand Years of Science.* Macmillan (G)
HOLMYARD. *Makers of Chemistry.* Oxford University Press (G)
HUTIN. *L'alchimie.* Presses Universitaires de France (F)
LENARD. *Great Men of Science.* Macmillan (U)
LIBBY. *An Introduction to the History of Science.* Houghton-Mifflin (U)
MACPHERSON. *Makers of Astronomy.* Oxford University Press (G)
MOORE. *A History of Chemistry.* McGraw-Hill (U)
SCHONLAND. *Flight of Thunderbolts.* Oxford University Press (G)
SHIPPEU. *The Great Heritage.* Viking (U)
SINGER. *The Story of Living Things.* Harper (U)
SINGER. *A Short History of Science to the Nineteenth Century.* Oxford University Press (G)
Various authors. *The History of Science.* Cohen & West (G)

2. PUPILS' TEXT-BOOKS and 'READERS' [2]

Basic Science Education Series. Row, Peterson (U)
Encyclopédie par l'image (Série). Hachette (F)
La joie de connaître (Série). Bourrelier (F)

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[1] Biographies of individual scientists have been omitted, but many are available and a few of them should be included in a school science library.

[2] A few very elementary books are included because they are essential for pupils who have not studied any Science prior to attendance at a secondary school.

New Playbooks of Science Series. Oxford University Press (G)
Oxford Visual Series. Oxford University Press (G)
Science on the March Series. Longmans (G)
The Wonderworld of Science Series. Scribners (U)
Understanding our World Series. Winston (U)

ALEXANDER & STREET. *Metals in the Service of Man*. Penguin (G)
ANDRADE & HUXLEY. *Simple Science*. Blackwell (G)
ANDRADE & HUXLEY. *More Simple Science*. Blackwell (G)
BALLAM & HERBERT. *The Story of a Thread of Cotton*. Penguin (G)
BARNARD & EDWARDS. *Basic Science*. Macmillan (U)
BAXTER. *Scientists against Time*. Little, Brown (U)
BEAUCHAMP & others. *Everyday Problems in Science*. Scott-Foresman (U)
BENEDICT. *Electronics for Young People*. McGraw-Hill (U)
BIBBY. *Active Human Biology*. Heinemann (G)
BIBBY. *Simple Experiments in Biology*. Heinemann (G)
BOULENGER. *Wonders of Sea Life*. Penguin (G)
BRANDWEIN & others. *Science for Better Living*. Harcourt, Brace (U)
BURNETT & others. *New World of Science*. Silver Burdett (U)
BURNS. *First Steps in Astronomy*. Ginn (U)
CALDWELL & CURTIS. *Everyday Science*. Ginn (U)
CARROLL. *Interpreting Science*. Winston (U)
CARSON. *The Sea around Us*. Staples (U)
CODISLE. *Modern Wonderbook of Trains and Railways*. Winston (U)
DANIEL. *General Science for Tropical Schools* (5 volumes and teacher's handbook). Oxford University Press (G)
DANIEL. *Health Science and Physiology for Tropical Schools*. Oxford University Press (G)
DE KRUIF. *The Microbe Hunters*. Pocket Books (U)
EBY. *The Physical Sciences*. Ginn (U)
FABRE. *Social Life in the Insect World*. Duckworth (G)
FABRE. *Wonders of Instinct*. Duckworth (G)
FREEMAN. *Invitation to Experiment*. Dutton (U)
GLASSTONE. *Chemistry in Daily Life*. Methuen (G)
GRANDPERRIN & GUYET. *Sciences appliquées et Travaux Pratiques*. Colin (F)
HARGREAVES. *The Size of the Universe*. Penguin (G)
HARTRIDGE. *Colours and How We See Them*. Bell (G)
HAWLEY. *Seeing the Invisible*. Knoff (U)
HEYS. *Chemistry Experiments at Home for Boys and Girls*. Harrap (G)
HOLMES & GIBBS. *A Modern Biology* (Tropical edition). Cambridge University Press (G)
HUNTER & WHITMAN. *Doorways to Science*. American Book Co. (U)
KELLOGG. *The Soils that Support Us*. Macmillan (U)
KIMBLE. *The Weather*. Penguin (G)
LADYMAN. *About a Motor Car*. Penguin (G)

LAZERGES. *Sciences d'observation.* Colin (F)
LEWELLEN. *You and Atomic Energy.* Children's Press (U)
MAETERLINCK. *The Life of the Ant.* Cassell (G)
MAETERLINCK. *The Life of the Bee.* Allen & Unwin (G)
MAETERLINCK. *The Life of the White Ant.* Allen & Unwin (G)
MANN & PIRIE. *The Science of Seeing.* Penguin (G)
MAYO. *The Story of Living Things.* Waverley Book Co. (G)
OBOURN & others. *Science in Everyday Life.* Van Nostrand (U)
OBRÉ. *Sciences naturelles.* Hachette (F)
ORIEUX. *Sciences d'observation.* Hachette (F)
PENDRAY. *Men, Mirrors and Stars.* Harper (U)
POTTER. *Young People's Book of Atomic Energy.* McBride (U)
ROWLAND. *Living Things for Lively Youngsters.* Cassell (G)
RYDER. *Mother Earth.* Hutchinson (G)
SCHNEIDER. *Everyday Machines and How They Work.* McGraw-Hill (U)
SHERWOOD TAYLOR. *Man's Conquest of Nature.* Elek (G)
SILVERMAN. *Magic in the Bottle.* Macmillan (U)
SKILLING & RICHARDSON. *Astronomy for Beginners.* McGraw-Hill (U)
SMART. *Astronomy.* Oxford University Press (G)
SMITH. *Beyond the Microscope.* Penguin (G)
SMITH. *Gas Turbines and Jet Propulsion for Aircraft.* Aircraft Books (U)
SMITH & others. *Science for Modern Living.* Lippincott (U)
SMITH & VANCE. *Science for Everyday Use.* Lippincott (U)
STACK. *Careers in Safety.* Funk & Wagnalls (U)
STARR. *First Book of Meteorology.* Harrap (G)
TOURAINE. *Eléments de Sciences Physiques et Naturelles.* Istra (F)
Various authors. *Boys' Book of Science and Invention.* Evans Bros. (G)
Various authors. *Internal Combustion Engines.* Odhams (G)
Various authors. *Miracles of Invention and Discovery.* Odhams (G)
VEALE & 'WREN'. *How 'Planes Fly.* Penguin (G)
WALKER. *Human Physiology.* Penguin (G)
WALKER. *The Physiology of Sex.* Penguin (G)
WHITEHOUSE & PRITCHARD. *General Science* (3 volumes). Oxford University Press (G)
WIGGLESWORTH. *Insect Physiology.* Methuen (G)
WILSON. *They Live in the Sea.* Collins (G)
WILSON. *Trees and Test-tubes: the Story of Rubber.* Holt (U)
WOOD & CARPENTER. *Our Environment: How We Use and Control It.* Allyn & Bacon (U)
YATES. *A Boy and a Battery.* Harper (U)

3. PRACTICAL [1]

BASSETT-LOWKE & MANN. *Marvellous Models.* Penguin (G)

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[1] The text-books and some of the 'readers' listed under heading 2 contain details of courses of, or suggestions for, experimental work.

BEAUCHAMP & others. *A Study Book—for Everyday Problems in Science.* Scott-Foresman (U)

BLACKWOOD. *Experiences in Science.* Harcourt, Brace (U)

CARROLL. *Workbook*—for *Understanding Our World.* Winston (U)

GOHM & PATTERSON. *Electric Models from Odds and Ends.* Penguin (G)

KALMUS. *Simple Experiments with Insects.* Heinemann (G)

LYNDE. *Science Experiences with Home Equipment.* International Textbook (U)

MEISTER & others. *Workbook*—for *The Wonderworld of Science.* Scribners (U)

MORGAN. *Simple Chemical Experiments.* Appleton-Century (U)

THORPE. *The Faraday Books of Practical Science.* Oxford University Press (G)

4. TEACHING METHOD, etc.

BLOUGH & BLACKWOOD. *Teaching Elementary Science.* Office of Education, Washington (U)

BLOUGH & BLACKWOOD. *Science Teaching in Rural and Small Town Schools.* Office of Education, Washington (U)

CHILDS. *Physical Constants.* Methuen (G)

CONANT. *Science and Common Sense.* Harvard University Press (U)

CONANT. *On Understanding Science.* Yale University Press (U)

DEWEY. *How We Think.* Heath (U)

DOWNING. *An Introduction to the Teaching of Science.* University of Chicago Press (U)

EDEN. *Elements of Tropical Soil Science.* Macmillan (G)

FOWLES. *Lecture Experiments in Chemistry.* Blakiston (U)

HEISS & others. *Modern Science Teaching.* Macmillan (U)

HOFF. *Secondary School Science Teaching.* Blakiston (U)

HUMBY & JAMES. *Science and Education.* Cambridge University Press (G)

HUNTER. *Science Teaching at Junior and Senior High School Levels.* American Book Co. (U)

KLICKSTEIN. *Sourcebook in Chemistry.* McGraw-Hill (U)

MAGIE. *Demonstration Experiments in Physics.* McGraw-Hill (U)

MAGIE. *Sourcebook in Physics.* McGraw-Hill (U)

National Society for the Study of Education. *A Program for Teaching Science.* University of Chicago Press (U)

National Society for the Study of Education. *Science Education in American Schools.* University of Chicago Press (U)

NOKES. *Science in Education.* Macdonald (G)

NORTON. *Star Atlas.* Gall & Inglis (G)

NUNN. *Handbook for Science Teachers.* Murray (G)

POWERS & LAYTON. *Teaching Science.* McGraw-Hill (U)

PRESTON. *The High School Science Teacher and His Work.* McGraw-Hill (U)

Progressive Education Association. *Science in General Education.* Appleton-Century (U)

RITCHIE. *Scientific Method.* Harcourt, Brace (U)
Science Masters' Association & I.A.A.M. *The Teaching of Science in Secondary Schools.* Murray (G)
SHELTON. *Theory and Practice of General Science.* Murby (G)
TWISS. *Principles of Science Teaching.* Macmillan (U)
UVAROV. *A Dictionary of Science.* Penguin (G)
Various authors. *A Dictionary of Biology.* Penguin (G)
Various authors. *The Teaching of General Science.*[1] Murray (G)
Various authors. *Whitaker's Almanack.* Whitaker (G)
WESTAWAY. *Science Teaching.* Blackie (G)
ZIM. *Science for Children and Teachers.* Association for Childhood Education (U)

5. LABORATORIES and APPARATUS [2]

ANSLEY. *Introduction to Laboratory Technique.* Macmillan (G)
BARKER & CHAPMAN. *Workshop Practice for the School and Laboratory.* Sidgwick & Jackson (G)
DUCKWORTH & HARRIES. *The Laboratory Workshop.* Bell (G)
E. H. Sheldon Co., Muskugan, Michigan. *Catalog.* (U)
MILLER & BLADES. *Methods and Materials for Teaching Biological Sciences.* McGraw-Hill (U)
MONOHAN. *Laboratory Layouts for the High School Sciences.* Office of Education, Washington (U)
NOKES. *Modern Glass Working.* Heinemann (G)
RICHARDSON & CAHOON. *Methods and Materials for Teaching General and Physical Science.* McGraw-Hill (U)
Science Masters' Association. *The Science Masters' Book* (2 volumes in each of the Series I, II, III). Murray (G)
STEPHENSON. *Suggestions for Science Teachers in Devastated Countries.* U.N.E.S.C.O.
SUTCLIFFE. *School Laboratory Management.* Murray (G)
SUTTON. *Demonstration Experiments in Physics.* McGraw-Hill (U)
Various authors. *Inventories of Apparatus and Materials for Teaching Science.* Volume I. U.N.E.S.C.O.
Various authors. *Safeguards in the Laboratory.* Murray (G)
Various authors. *The Construction of Laboratory Apparatus for Schools.* Portfolios I and II. U.N.E.S.C.O.
William Welch Co., Chicago, Illinois. *Catalog.* (U)
WOODRING & others. *Enriched Teaching of Science in the High School.*[3] Bureau of Publications, Columbia University (U)

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[1] Includes detailed suggestions for syllabuses.

[2] Details of laboratory organization and technique are also to be found in several of the books listed under heading 4.

[3] Mainly bibliographical (all aspects of science).

6. PERIODICALS

Discovery (G)
Meccano Magazine (G)
Model Engineering (G)
New Biology—Penguin[1] (G)
Popular Science Monthly (U)
Revue Scientifique (F)
School Science and Mathematics (U)
Science Education (U)
Science et Vie (F)
Science Review—Penguin[1] (G)
The American Biology Teacher (U)
The Journal of Chemical Education (U)
The School Science Review (G)
The Science Teacher (U)

Note.—Science teachers should always be on the alert for the publication of suitable books in the pupils' mother tongue, and of reference books particularly appropriate to their own region. The latter category is growing rapidly with increase of scientific knowledge, as shown by such titles as *Indian Hill Birds* (Salim Ali, Oxford University Press, India), *West African Botany* (Irvine, Oxford University Press), *Some Wild Flowers of Kenya* (Jex-Blake, Longmans).

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[1] Published occasionally.

APPENDIX G

The Prevention of Fire

However skilful a teacher may be, neglect of any possible precaution is a sign of ignorance. Fire-extinguishers should be tested regularly; tins of sand should not be too heavy for pupils to lift; the laboratory should have two exits; periodical fire-drill is desirable—all these should be kept in mind. The teacher must give frequent emphasis to correct laboratory procedure such as the following:

(1) Benches should be kept clear of unnecessary material, particularly of an inflammable nature.

(2) Experiments involving a source of heat should never be left unattended.

(3) Hot, burning or reactive substances should never be put in a sink or a waste-box. (Receptacles for waste are best made of tins, preferably painted, those for paper being distinct from those for other substances.)

(4) Mains services must be turned off when use of the laboratory is finished for the day.

(5) Apparatus must always be held firmly in the proper way. (For example, a flask standing on a wire gauze on a tripod must be supported by a clamp attached to a retort stand.)

(6) Special care must be taken with explosive or inflammable substances. Moreover, the arrangements should be such as to reduce danger to a minimum in case of spilling or breakage.

(7) Inflammable liquids should be heated only in round-bottomed flasks. A water- or sand-bath should always be used instead of a naked flame, and the process is most safely carried out in a fume-cupboard with the window shut.

(8) Very hot material may be placed on an asbestos pad but never directly on the bench top.

(9) Waste liquids must be disposed of with care. Even when cool they must be thoroughly washed away.

(10) Waste sodium, potassium, phosphorus, magnesium, lighted matches, etc., must be rendered harmless before being thrown away.

(11) Round flasks should never be left where they may act as lenses to concentrate the sun's rays.

N.B. The teacher should be the last to leave the laboratory. He is well advised to adopt the rule of scouting and 'take a last look round'. (Methods of dealing with fires are discussed in Chapter XI, page 277.)

A list, similar to the above, may be compiled as rules for pupils' observance, and be posted on the laboratory notice board.

APPENDIX H

The First-Aid Kit

The following items are recommended as the contents of a laboratory first-aid cupboard. If the cupboard is kept locked, the key should be secured to it (by adhesive tape or some other method) so that it cannot be mislaid.

Regular inspection of the cupboard is necessary to ensure thorough cleanliness and replenishment and good condition of the contents. To facilitate checking it is advisable to have a list of contents on the inside of the cupboard door. Labels on bottles should give not only the name of the substance but, where necessary, the purpose, the dose, the strength of solution, etc. (see Chapter XI, page 278).

Bandages; various sizes. (Best kept in an air-tight jar.)
Brush, camel-hair, small.
Cotton wool, absorbent; a roll. (Best kept in an air-tight jar.)
Dressings, sterilized. (Must be kept in an air-tight jar.)
Dropper—pipette for eye drops.
Eyebath.
Forceps—tweezers, pair of.
Gauze, medicated; a roll or several pieces. (Best kept in an air-tight jar.)
Lint, surgical; a roll. (Best kept in an air-tight jar.)
Plaster, adhesive; roll ½″ or 1″ wide or both. (Best kept in an air-tight jar.)
Safety-pins; various sizes, 1 dozen. (Best kept on cloth smeared with Vaseline or engine-oil, in an air-tight jar.)
Scissors, sharp-pointed, pair of.
Wash-bottle of distilled water.
Jelly (*or cream*)—*for burns*—as purchased or obtained from doctor or dispenser.
Sal volatile—bottle as purchased.
Bottles, 4 oz. wide-mouth, of solids:
    Mustard.   *Salt, common.*   *Sodium bicarbonate.*
Bottles, 4 oz. narrow-mouth, of liquids:
    Castor oil.   *Glycerine.*   *Milk of magnesia.*

Bottles, 4 oz. narrow-mouth, of solutions:

Boric acid, 1%. (1 g. of acid dissolved in 100 ml. of distilled water.)

Iodine—tincture of. (2·5 g. of potassium iodide dissolved in a little distilled water; 2·5 g. of iodine dissolved in the solution, which is then made up to 100 ml. with ethyl alcohol.)

Silver nitrate, dilute. (An approximately deci-normal solution consists of 1·7 g. of the nitrate in 100 ml. of distilled water.)

Sodium bicarbonate, 1%. (1 g. solid in 100 ml. of distilled water.)

Bottles, 16 oz. narrow-mouth, of solutions:

Acetic acid, 1%. (5 ml. of glacial acetic acid in 500 ml. of distilled water.)

Sodium bicarbonate, saturated. (Distilled water standing over slight excess of solid in the bottle.)

The above list is sufficient for a General Science laboratory. A few additional items may be required in the case of a laboratory used for more advanced chemistry.

APPENDIX J

Physical Data

I. DENSITIES

(1) *Densities of some common substances*

(a) Elements

	Grams per c.c.
Aluminium	2·7
Carbon (diamond)	3·5
Copper	8·9
Gold	19·3
Iron	7·8
Lead	11·4
Magnesium	1·7
Manganese	7·4
Mercury	13·6
Platinum	21·5
Silver	10·5
Sulphur	1·9
Tin	7·3
Zinc	7·1

(b) Miscellaneous solids

	Grams per c.c.
Brass	8·5
Cork	0·22–0·26
Ebonite	1·8
Glass, crown	2·4–2·6
,, , flint	2·9–4·5
Granite	2·5–3·0
Ice	0·917
Iron, cast	7·1–7·7
Marble	2·5–2·8
Naphthalene	1·15
Paraffin wax	0·89–0·93
Sand	2·63
Wood, cedar	0·5–0·6
,, , mahogany	0·6–0·8

(c) Liquids

	Grams per c.c.
Benzene	0·87
Brine (saturated)	1·20
Ether	0·73
Ethyl alcohol	0·80
Glycerine	1·26
Kerosene	0·80
Methylated spirit	0·83
Oil, castor	0·97
,, , linseed	0·94
,, , olive	0·92
,, , palm	0·92
Turpentine	0·87
Water	1·00

(d) Gases

	Grams per litre at 0° C. and 760 mm.
Air	1·293
Carbon dioxide	1·96
Carbon monoxide	1·25
Chlorine	3·214
Helium	0·179
Hydrogen	0·0899
Hydrogen sulphide	1·53
Nitrogen	1·251
Oxygen	1·429
Sulphur dioxide	2·93

(2) *The density of water at various temperatures*

Temperature ° C.	*Grams per c.c.*
0	0·999
4	1·000
15	0·999
30	0·996
50	0·988
100	0·958

(3) *Densities of various aqueous solutions*
(20° C. to 25° C. approx.)

Concentration	*Hydrochloric acid*	*Nitric acid*	*Sulphuric acid*
1N	1·017	1·033	1·03
2N	1·035	1·07	1·06
5N	1·085	1·16	1·16
10N	1·16	1·305	1·29
	Ammonium hydroxide	*Sodium hydroxide*	*Sodium carbonate*
1N	0·992	1·043	1·052
2N	0·985	1·088	1·103
5N	0·964	1·22	
10N	0·932	1·43	
	Sodium chloride	*Barium chloride*	*Ammonium chloride*
1N	1·042	1·23	1·015
2N	1·086		1·03
	Copper sulphate	*Silver nitrate*	*Lead acetate*
1N	1·04	1·152	1·295
2N	1·18		

See also '*Notes on laboratory solutions—Bench reagents*', page 266.

II. PRESSURES

(4) *Pressure of saturated water vapour at different temperatures (millimetres of mercury)*

° *C.*	0	1	2	3	4	5	6	7	8	9
0	4·6	4·9	5·3	5·7	6·1	6·5	7·0	7·5	8·0	8·6
10	9·2	9·8	10·5	11·2	12·0	12·8	13·6	14·5	15·5	16·5
20	17·5	18·6	19·8	21·0	22·3	23·7	25·1	26·7	28·3	29·9
30	31·7	33·6	35·5	37·6	39·8	42·0	44·4	46·9	49·5	52·3
	0	2	4	6	8	10	12	14	16	18
40	55·1	61·3	68·1	75·4	83·5	92·3	102	112	123	135
60	149	163	179	195	214	233	254	277	301	327
80	355	384	416	450	487	525	567	611	657	707
100	760	815	875	938	1004	1075	1149	1227	1310	1397

(e.g. the vapour pressure of water at 24° C. is 22·3 mm. of mercury, and the vapour pressure of water at 54° C. is 112 mm. of mercury.)

(5) *Boiling point of water at different pressures*

Pressure (mm. of mercury)	*Boiling point (° C.)*	*Pressure (mm. of mercury)*	*Boiling point (° C.)*
780	100·7	720	98·5
770	100·4	710	98·1
760	100·0	700	97·7
750	99·6	690	97·3
740	99·3	680	96·9
730	98·9	670	96·5

See also table (14), page 360.

III. HYGROMETRY

(6) *Weight of water (in grams) in* 1 *cubic metre of saturated air at* 760 *mms. pressure*

Temperature of air (° C.)	0	1	2	3	4	5	6	7	8	9
0	4·8	5·2	5·5	5·9	6·3	6·8	7·2	7·8	8·2	8·7
10	9·3	9·9	10·6	11·3	12·0	12·7	13·5	14·3	15·2	16·1
20	17·1	18·1	19·2	20·4	21·5	22·8	24·1	25·5	26·9	28·4
30	30·0	31·7	33·4	35·3	37·2	39·2	41·3	43·5	45·8	48·3

e.g. 1 cubic metre of air saturated with water vapour at 760 mm. pressure and 17° C. contains 14·3 g. of water.

7 (*a*) *Relative humidity*

Temperature of dry bulb (° F.)	*Depression of the i.e. difference between wet*																	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
140	97	95	92	89	87	84	82	79	77	75	73	70	68	66	64	62	60	58
135	97	95	92	89	86	84	81	79	76	74	72	69	67	65	63	61	59	57
130	97	94	91	89	86	83	81	78	76	73	71	69	66	64	62	60	57	55
125	97	94	91	88	85	83	80	78	75	72	70	68	65	63	61	58	56	54
120	97	94	91	88	85	82	79	77	74	72	69	67	64	62	59	57	55	53
118	97	94	91	88	85	82	79	76	74	71	69	66	63	61	59	56	54	52
116	97	94	90	87	84	82	79	76	73	71	68	65	63	61	58	56	54	51
114	97	94	90	87	84	81	79	76	73	70	68	65	63	60	58	55	53	51
112	97	94	90	87	84	81	78	75	73	70	67	65	62	59	57	55	52	50
110	97	93	90	87	84	81	78	75	72	69	67	64	61	59	56	54	51	49
108	97	93	90	87	84	81	78	75	72	69	66	63	61	58	56	53	51	49
106	96	93	90	87	84	80	77	74	71	68	66	63	60	58	55	52	50	48
104	96	93	90	86	83	80	77	74	71	68	65	62	60	57	54	52	49	47
102	96	93	90	86	83	80	77	73	70	67	65	62	59	56	54	51	48	46
100	96	93	89	86	82	79	76	73	70	67	64	61	58	55	53	50	47	45
98	96	93	89	86	82	79	76	72	69	66	63	60	57	54	52	49	46	44
96	96	93	89	85	82	78	75	72	68	65	62	59	57	54	51	48	45	43
94	96	93	89	85	81	78	75	71	68	65	62	59	56	53	50	47	44	42
92	96	92	88	85	81	78	74	71	67	64	61	58	55	52	49	46	43	40
90	96	92	88	84	81	77	74	70	67	63	60	57	54	51	48	45	42	39
88	96	92	88	84	80	77	73	69	66	63	59	56	53	50	47	44	41	38
86	96	92	88	84	80	76	72	69	65	62	58	55	52	49	45	42	39	36
84	96	92	87	83	79	76	72	68	64	61	57	54	51	47	44	41	38	35
82	96	91	87	83	79	75	71	67	64	60	56	53	49	46	43	40	36	33
80	96	91	87	83	79	74	70	66	63	59	55	52	48	45	41	38	35	31
78	95	91	86	82	78	74	70	66	62	58	54	50	47	43	40	36	33	30
76	95	91	86	82	78	73	69	65	61	57	53	49	45	42	38	34	31	28
74	95	90	86	81	77	72	68	64	60	56	52	48	44	40	36	33	29	26
72	95	90	85	80	76	72	67	63	58	54	50	46	42	38	34	31	27	23
70	95	90	85	80	75	71	66	62	57	53	49	44	40	36	32	28	24	21
68	95	90	84	79	75	70	65	60	56	51	47	43	38	34	30	26	22	18
66	95	89	84	79	74	69	64	59	54	50	45	41	36	32	28	23	20	16
64	94	89	83	78	73	68	63	58	53	48	43	39	34	30	25	21	17	13
62	94	88	83	77	72	67	61	56	51	46	41	37	32	27	23	18	14	10
60	94	88	82	77	71	65	60	55	50	44	39	34	29	25	20	15	11	6
58	94	88	82	76	70	64	59	53	48	42	37	31	26	22	17	12	7	2
56	94	87	81	75	69	63	57	51	46	40	35	29	24	19	13	8	3	
54	93	87	80	74	68	61	55	49	43	38	32	26	21	15	10	5		
52	93	86	79	73	66	60	54	47	41	35	29	23	17	12	6			
50	93	86	79	72	65	59	52	45	38	32	26	20	14	8	2			
48	92	85	77	70	63	56	49	42	36	29	22	16	10	4				
46	92	84	77	69	62	54	47	40	33	26	19	12	6					
44	92	84	75	68	60	52	45	37	29	22	15	8						
42	91	83	74	66	58	50	42	34	26	18								
40	91	82	73	65	56	47	39	30										

(percentage) — ° *F.*

wet bulb (° F.)
and dry bulb readings

19	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48	50	52	54	56
56	54	51	47	44	40	37	35	32	29	26	24	22	19	17	15	13	11	9	8
55	53	49	46	42	39	36	33	30	27	24	22	20	17	15	13	11	9	7	5
53	51	48	44	41	37	34	31	28	25	22	20	17	15	13	10	8	6	4	2
52	50	46	42	39	35	32	29	26	23	20	17	15	12	10	8	6	3		
51	48	44	41	37	33	30	27	23	20	18	15	13	10	8	5	3			
50	48	44	40	36	32	29	26	22	19	16	14	11	8	6	3				
49	47	43	39	35	31	28	25	21	18	15	12	10	7	4	2				
48	46	42	38	34	30	27	23	20	17	14	11	8	6	3					
48	46	41	37	33	29	26	22	19	16	13	10	7	4	2					
47	45	40	36	32	28	25	21	18	14	11	8	5	3						
46	44	40	35	31	27	23	20	16	13	10	7	4							
45	43	39	34	30	26	22	18	15	11	8	5	2							
44	42	37	33	29	25	21	17	13	10	7	4								
43	41	36	32	28	23	19	16	12	8	5	2								
42	40	35	31	26	22	18	14	10	7	3									
41	39	34	29	25	20	16	12	9	5										
40	38	33	28	23	19	15	10	7	3										
39	36	31	26	22	17	13	9	5											
38	35	30	25	20	15	11	7	3											
36	34	28	23	18	14	9	5												
35	32	27	21	16	12	7	2												
33	31	25	19	14	10	5													
32	29	23	18	12	7	2													
30	27	21	16	10	5														
28	25	19	13	8	2														
26	23	17	11	5															
24	21	15	8	2															
22	19	12	6																
20	16	9	3																
17	14	7																	
15	11	3																	
12	8																		
9	5																		
5																			
2																			

7 (*b*) *Relative humidity* (*percentage*) — ° *C.*

Temperature of dry bulb (° C.)	*Depression of the wet bulb* (° C.)														
	1	2	3	4	5	6	7	8	9	10	12	14	16	18	20
50	94	89	84	79	74	70	65	61	57	53	46	40	33	28	22
45	94	88	83	78	73	68	63	59	55	51	42	35	28	22	16
40	93	88	82	77	71	65	61	56	52	47	38	31	23	16	10
35	93	87	80	75	68	62	57	52	47	42	33	24	16	8	
30	92	86	78	72	65	59	53	47	41	36	26	16	8		
25	91	84	76	69	61	54	47	41	35	29	17	6			
20	90	81	73	64	56	47	40	32	26	18	5				
15	89	79	68	59	49	39	30	21	12	4					
10	87	75	62	51	38	27	17	5							

To find by interpolation values not shown in Tables 7(*a*) *and* 7(*b*)—Intermediate values are found by putting the appropriate figure in the series, and this is often merely a matter of finding the 'half-way' figure by simple proportion. For example: dry bulb 94° F., wet bulb 86·5° F., i.e. a depression of 94−86·5 = 7·5° F. The nearest figures given in the Table are shown in ordinary type, the interpolated figures in heavy type:

Dry bulb	*Depression*		
	7	**7·5**	8
94	75	**73**	71

Simple proportion gives the half-way figure, showing the relative humidity as 73 per cent.

Similarly, if the dry bulb reads 93° F. and the wet bulb 75° F., i.e. a depression of 93 − 75 = 18° F.:

Dry bulb	*Depression* 18
94	42
93	**41**
92	40

Here again simple proportion gives the half-way figure, and in this case the relative humidity is 41 per cent.

For a depression of 10·5° F. at a dry bulb temperature of 73° F., the figures are:

Dry bulb	*Depression* 10	*10·5*	11
74	56	***54***	52
73		***53***	
72	54	***52***	50

When the figures do not work out exactly, approximations must be used, the relative humidity always being given as a whole number. In a doubtful case, the conventional rule is to choose the *odd* number. For instance: dry bulb 80° F.; depressions of 1 and 2 degrees show humidities of 96 and 91 per cent. respectively in the Table. Thus the value for a depression of 1·5° F. might be either 94 or 93 per cent. It is customary to choose 93 per cent.

More detailed tables than those given here are used at climatological stations and in meteorological offices. But even when these are consulted, some interpolation is often necessary, since thermometers are read to the nearest tenth of a degree.

IV. SURFACE TENSION

(8) The surface tension of water at 15° C. is 73·5 dynes per cm.
(9) „ „ „ „ mercury „ „ 465 „ „ „

V. HEAT

(10) *Equivalent temperatures on different scales*

	Absolute	*Centigrade*	*Fahrenheit*	*Réamur*
Absolute zero	0° A.	– 273° C.	– 459° F.	– 218° R.
Fahrenheit zero . . .	255° A.	– 18° C.	0° F.	– 14° R.
Freezing point of water .	273° A.	0° C.	32° F.	0° R.
Boiling point of water .	373° A.	100° C.	212° F.	80° R.

(11) *Centigrade to Fahrenheit conversion table*

° *C.*	° *F.*	° *C.*	° *F.*	° *C.*	° *F.*	° *C.*	° *F.*
0	32	26	79	51	124	76	169
1	34	27	81	52	126	77	171
2	36	28	82	53	127	78	172
3	37	29	84	54	129	79	174
4	39	30	86	55	131	80	176
5	41	31	88	56	133	81	178
6	43	32	90	57	135	82	180
7	45	33	91	58	136	83	181
8	46	34	93	59	138	84	183
9	48	35	95	60	140	85	185
10	50	36	97	61	142	86	187
11	52	37	99	62	144	87	189
12	54	38	100	63	145	88	190
13	55	39	102	64	147	89	192
14	57	40	104	65	149	90	194
15	59	41	106	66	151	91	196
16	61	42	108	67	153	92	198
17	63	43	109	68	154	93	199
18	64	44	111	69	156	94	201
19	66	45	113	70	158	95	203
20	68	46	115	71	160	96	205
21	70	47	117	72	162	97	207
22	72	48	118	73	163	98	208
23	73	49	120	74	165	99	210
24	75	50	122	75	167	100	212
25	77						

(12) *Melting points, boiling points and specific heats of some common substances*

Substance	*Melting point (° C.)*	*Boiling point (° C.)*	*Specific heat (Calories per gram)*
(*a*) *Elements*			
Aluminium	660	2200	0·21
Carbon, diamond	3500	3927	0·16
Copper	1084	2310	0·091
Gold	1063	2530	0·031
Helium	− 272	− 269	
Hydrogen	− 259	− 253	
Iron	1527	3235	0·11
Lead	327·4	1755	0·03
Magnesium	649	1107	0·246
Manganese	1242	1900	0·112
Mercury	− 38·9	356·7	0·033
Nitrogen	− 210	− 196	
Oxygen	− 218	− 183	
Platinum	1774	4300	0·032
Silver	960·5	2152	0·056
Sulphur	115	444·6	0·163
Tin	232	2270	0·054
Zinc	419·5	913	0·092
(*b*) *Solids* (*miscellaneous*)			
Brass			0·089
Ebonite			0·4
Glass			0·16
Ice	0	100	0·5
Iron, cast	1527	2450	0·11
Marble			0·22
Naphthalene	80	218	
Paraffin wax			0·69
(*c*) *Liquids* (*miscellaneous*)			
Benzene	5	80	
Ether	− 118	35	
Ethyl alcohol	− 115	78	0·58
Glycerine	17	290	0·58
Kerosene			0·51
Methylated spirit			0·55
Oil, castor		316	0·51
„ , palm, and olive			0·47
Turpentine			0·42
Water	0	100	1·00

(13) *Latent heats*

Substance	*Calories per gram*
Ice/water	80
Water/steam	539
Naphthalene solid/liquid	35
Ethyl alcohol liquid/gas	205

(14) *Boiling point of water at various heights and pressures*

Height (metres above M.S.L.[1]*)*	*Pressure (millibars)*	*Pressure (mm. of mercury)*	*Temperature of boiling water (° C.)*
0	1013	760	100
1000	899	674	97
2000	795	598	94
3000	701	528	90
4000	616	467	87
5000	540	411	84
10000	264	205	67
15000	120	95	50

[1] M.S.L.—Mean sea level.

(15) *Coefficients of expansion*

(a) Of length (linear)		*(b) Of volume* (cubical)	
Solids	α	*Liquids*	γ
Aluminium	26×10^{-6}	Alcohol	0·0011
Brass	19 ,,	Glycerine	0·00053
Carbon, diamond	7·9 ,,	Kerosene	0·0011
Copper	17 ,,	Methylated spirit	0·0011
Glass	8·5 ,,	Mercury	0·000182
Gold	14 ,,	Turpentine	0·00097
Ice	50 ,,	Water (5–10° C.)	0·000053
Iron	12 ,,	(10–20° C.)	0·000150
,, cast	10 ,,	(20–40° C.)	0·000362
Lead	29 ,,	(40–60° C.)	0·000458
Magnesium	25 ,,	(60–80° C.)	0·000587
Pyrex glass	3 ,,		
Silica	0·4– 0·5 ,,		
Steel	10·5–11·6 ,,		
Silver	19 ,,		
Tin	22 ,,		
Zinc	28 ,,		

Note—To obtain the coefficients of cubical (volume) expansion of solids, the coefficients of linear (length) expansion are multiplied by 3.

(16) *Thermal conductivities*

Substance	*Conductivity (Calories per cm. per second per ° C.)*	
Silver	0·97	CONDUCTORS ↑
Copper	0·92	
Gold	0·7	
Aluminium	0·5	
Zinc	0·27	
Brass	0·26	
Iron	0·16	
Tin	0·16	
Steel	0·11	
Lead	0·08	
Ice	0·005	NON-CONDUCTORS ↓
Glass	0·0017	
Mahogany	0·0005	
Ebonite	0·00038	
Rubber	0·00031	
Cork	0·00012	
Silk	0·00009	
Wool	0·00009	
Eiderdown	0·00005	

VI. LIGHT

(17) *Speed of light*

300,000,000 metres per second
or 186,000 miles per second

(18) *Some refractive indices*

Substance	*Refractive Index*
Aniline	1·59
Carbon disulphide	1·63
Diamond	2·42
Ethyl alcohol	1·36
Glass, crown-flint	1·52–1·65
Ice	1·31
Kerosene	1·44
Turpentine	1·48
Water	1·33

VII. SOUND

(19) *Speed of sound*

Medium	*Velocity (cm. per sec.)*
Air	$3{\cdot}13 \times 10^4$
Water	$14{\cdot}10 \times 10^4$
Steel	$47\text{–}52 \times 10^4$
Glass	$50\text{–}53 \times 10^4$
Wood	45×10^4

(20) *Frequency of musical notes (Laboratory scale)*

Note	*c*	*d*	*e*	*f*	*g*	*a′*	*b′*	*c′*
Frequency	256	288	320	341	384	427	480	512
Ratio of frequency of note compared with c	1	9/8	5/4	4/3	3/2	5/3	15/8	2

(21) *Conditions for harmony*

Notes	*Interval* (*as named by the musician*)	*Ratio of frequencies* (*lower to higher note*)
c e	major third	four-fifths
c f	perfect fourth	three-quarters
c g	perfect fifth	two-thirds
e c	minor sixth	five-eighths
c a	major sixth	three-fifths
c c	octave	one half

Note—When the ratio of the frequencies of two notes is a simple fraction, harmony results. Harmony is not a matter of personal opinion, but of physical measurement. Musicians and physicists approach the subject of harmony from different points of view, and the names given to intervals by musicians do not correspond to the arithmetical ratios of the frequencies of the notes involved. The table above helps the musical pupil to avoid confusion.

VIII. ELECTRICITY

(22) *Characteristics of copper wire*

Standard Wire Gauge (*S.W.G.*)	*Diameter* (*mm.*)	*Resistance* (*ohms per metre*)	*Safe Current* (*amps.*)	*Fusing Current* (*amps.*)
8	4·06			
10	3·25			
14	2·03			
18	1·21	0·015	4·2	20
20	0·91	0·026	2·6	11
22	0·71	0·033	1·7	7
26	0·45	0·06	0·7	3
32	0·27	0·29	0·2	
36	0·19	0·59	0·15	

(23) *Approximate resistance of other wires*

To obtain the approximate resistance (in ohms) of wires of other materials, the figures under 'Resistance in ohms per metre', for copper (Table 22), should be multiplied by the factors shown below:—

Material	*Factor*
Constantan	30
Contra	30
Eureka	30
Manganin	25
Nichrome	60

(24) *Sizes of flexible conductors*

Bell wire, for circuit; up to 6 volts:
6 strands of 36 S.W.G. copper wire (6/36)
Ordinary wire, for circuits up to 250 volts:
To carry 400 watts (14/36)
To carry 600 watts (23/36)
To carry 1000 watts (40/36)

(25) *Electromotive force (E.M.F.) of cells*

Primary cells	*E.M.F. (volts)*
Bichromate	2·0
Bunsen	1·9
Daniell	1·07
Leclanché, wet	1·5
„ , dry battery	1·5
Secondary cells	***Voltage***
Nickel-iron (NiFe)	1·2
Lead	1·9–2·2

(26) *Carrying capacity of pure tin fuse wire*

Gauge (S.W.G.)	*Capacity (amps.)*
24	5
26	4
28	3
32	2
36	1

(27) *Electro-chemical equivalents*

Element	*Equivalent (gram per sec. per amp.)*
Silver	0·001118
Copper	0·00033
Oxygen	0·0000829
Hydrogen	0·00001045

(96,494 amp.-seconds will deposit one equivalent weight in grams.)

(28) *Voltages to produce sparks in air*

Conditions: Average temperature and pressure
Sparks between pointed leads.

Length of Spark (inches)	*Potential (volts)*
0·25	5000
0·5	15000
1·0	30000
2·0	50000
6·0	100000

(29) *Molecular dimensions*

Diameter of a molecule of hydrogen: $2{\cdot}4 \times 10^{-8}$ cm.
Diameter of a molecule of water: $4{\cdot}1 \times 10^{-8}$ cm.

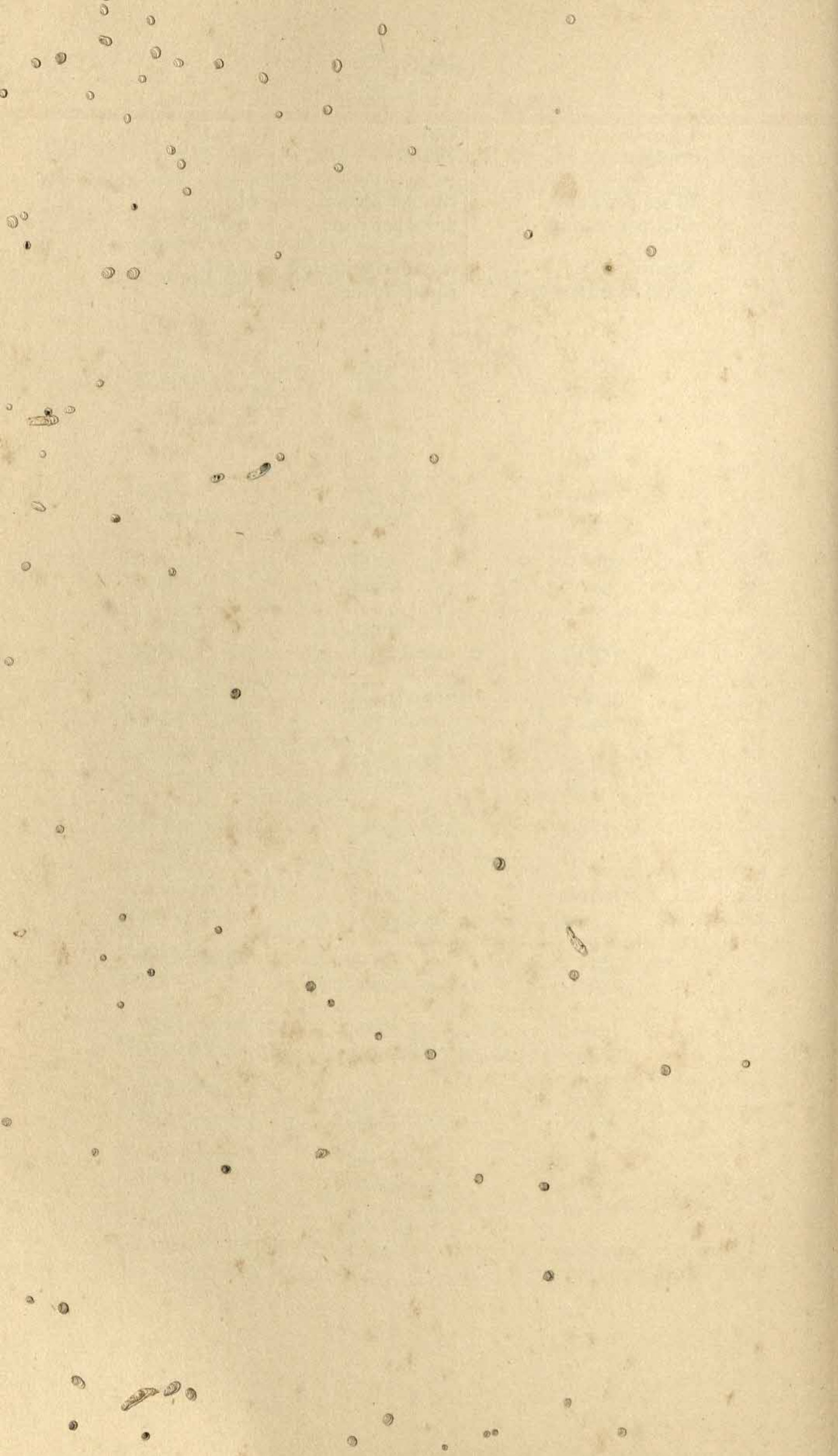
IX. CONVERSION FACTORS

The unit in the first column is multiplied by the conversion factor shown in order to obtain the equivalent number of the unit in the second column:—

e.g. 6 inches = 6 × 2·5400 centimetres
15 pounds per cubic ft. = 15 × 0·01602 grams per c.c.

Inches	centimetres	2·5400
Centimetres . . .	inches	0·3937
Yards	metres	0·9144
Metres	yards	1·094
Miles	kilometres	1·609
Kilometres	miles	0·62137
Pints	litres	0·5682
Litres	pints	1·760
Ounces	grams	28·35
Grams	ounces	0·0353
Pounds (Br.) . . .	kilogrammes	0·4536
Kilogrammes . . .	pounds	2·205
Gallons (Br.) . . .	cubic feet	0·1602
Cubic feet	gallons	6·24
Gallons (U.S.A.) . .	gallons (Br.)	0·8331
Gallons (Br.) . . .	gallons (U.S.A.)	1·2
Pounds per cu. ft. .	grams per c.c.	0·01602
Grams per c.c. . .	pounds per cu. ft.	62·43
Pounds weight . .	dynes	4·448 × 10^{5}
Dynes	pounds weight	2·248 × 10^{-6}
Pounds per sq. in. .	grams per sq. cm.	70·306
Grams per sq. cm. .	pounds per sq. in.	0·01422
Foot-pounds . . .	joules	1·356
Joules	foot-pounds	0·7372
Horse power . . .	kilowatts	0·746
Kilowatts	horse power	1·34
B.Th.U.	calories	252
Calories	B.Th.U.	0·003968

Calories	joules	4·18
Joules	calories	0·239
Miles per hour	cm. per second	44·70
Cm. per second	miles per hour	0·02237
Square inches	square centimetres	6·4516
Square centimetres	square inches	0·1550



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